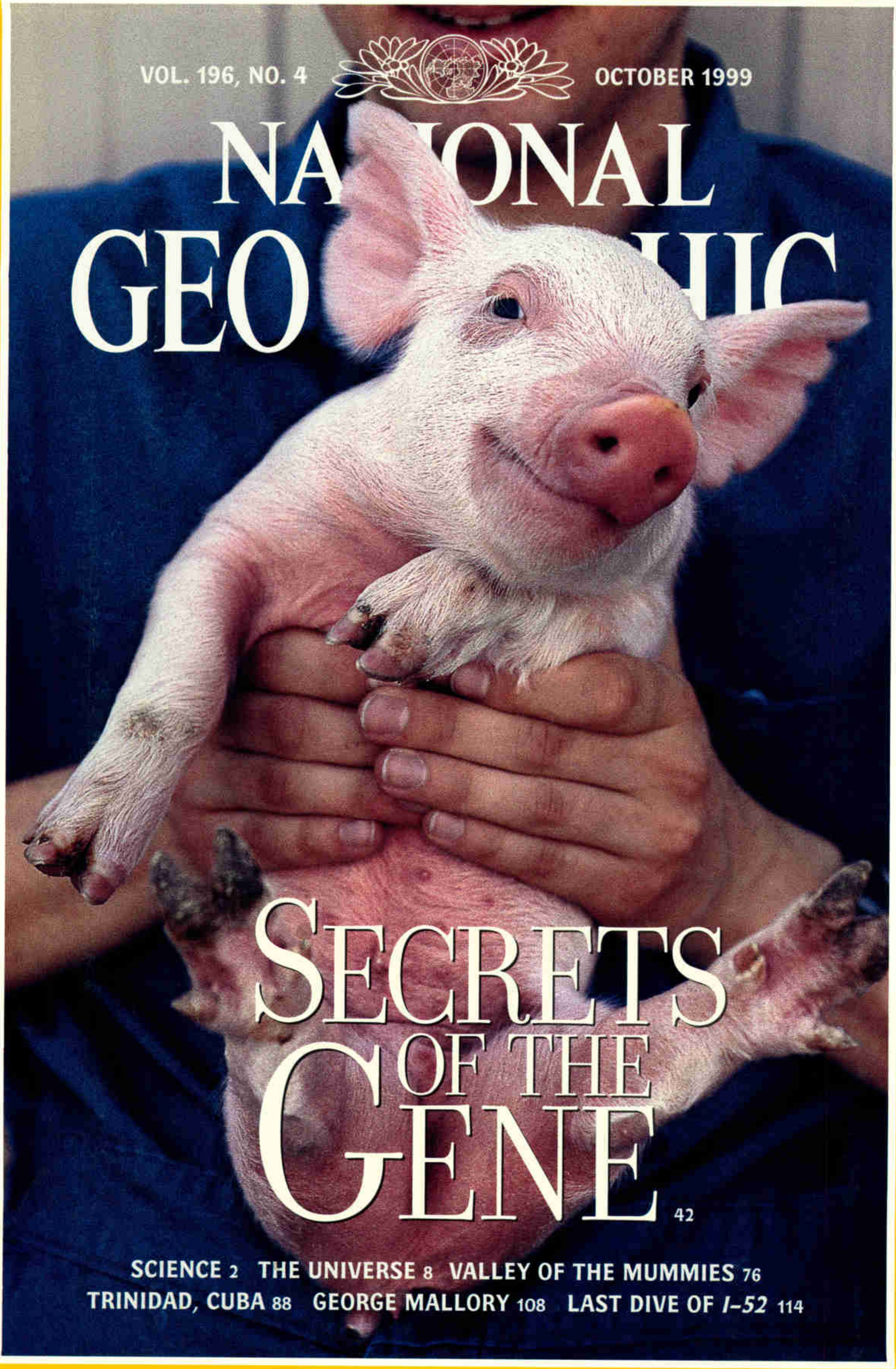
MILLENNIUM SUPPLEMENT: THE UNIVERSE

VOL. 196, NO. 4 OCTOBER 1999

NATIONAL GEOGRAPHIC



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OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D.C.

MILLENNIUM IN MAPS

THE MILKY WAY

NATIONAL GEOGRAPHIC SOCIETY

Home galaxy of Earth, the Milky Way is a spiral-shaped system of a few hundred billion stars. Bright regions of recently formed stars highlight its arms, while older stars explode or expel their outer layers as beautiful planetary nebulae, then fade away and die. A thick swarm of orange and red stars marks the galactic bulge, encapsulating the star-packed galactic center. At its core may lie a black hole, a region so dense that not even light can escape its gravitational pull. All objects in the Milky Way orbit the galactic center, much like planets in Earth's solar system revolve around the sun. But the scale is staggering: Light from a star at one edge of the galaxy takes about 100,000 years to reach the opposite side.

2000 NATIONAL GEOGRAPHIC

M80
HUBBLE HERITAGE TEAM

1

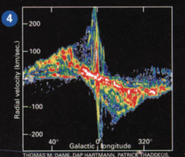
GUIDE TO THE GALAXY

1 Far beyond the galactic disk, yet drawn by its gravity, lone stars and globular clusters wander the galaxy's halo. Regions of dark matter—unseen but felt through its gravitational effects—extend beyond that.

2 Vast clouds of interstellar dust block much of our night sky view of the Milky Way, which from our position in the flat galactic disk appears as a fuzzy band of light. Infrared satellites can see through the dust to reveal the galaxy's structure.

3 Earth's orbit around the sun lies at a severe angle to the galactic plane.

4



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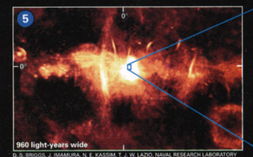

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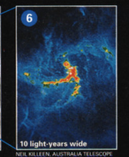
6



NEIL KILLEEN, AUSTRALIA TELESCOPE NATIONAL FACILITY; F. N. Y. LO, UNIVERSITY OF ILLINOIS

A TURBULENT HEART

4 A graph based on a radio survey reveals the whirlpool motion of molecular gas in the inner part of our galaxy: gas moving away from Earth (top half) and toward Earth (bottom half). The densest gas appears white; least dense, blue.

5 Massive amounts of energy are released near the center of the Milky Way, producing electrons that race along magnetic field lines, illuminating remnants of stellar explosions.

6 Probing even deeper into the core, a radio image details a spiral of hot gas that is falling toward what may be a black hole some 2.6 million times as massive as the sun.

This computer-generated image of the Milky Way—one perspective of a 3-D model newly compiled for NATIONAL GEOGRAPHIC—incorporates the actual positions of hundreds of thousands of stars and nebulae.

- Globular star cluster
- Interstellar gas and dust
- Nebula
- Younger star region (OB stars)
- Molecular cloud
- Galactic bulge or center (older star region)

Reference numbers for galaxies, nebulae, and star clusters
IC (Index Catalog)
M (Messier)
NGC (New General Catalog)

Coordinate system centered on galactic center

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PLANETARY NEBULA M2-9

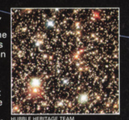
BRUCE BALICK, UNIVERSITY OF WASHINGTON; VINCENT ICKE, LEIDEN UNIVERSITY; GARRETT MELLEMA, STOCKHOLM UNIVERSITY; NASA

Exotic kaleidoscopes of the Milky Way, colorful nebulae and star clusters are found throughout Earth's galaxy. Even a run-of-the-mill star may eventually produce a nebula of surpassing beauty.

7 Just as our sun will do in its death throes some five billion years from now, a dying star expanded into a red giant and was transformed into the nebula M2-9 (above). At its center shines a small, hot core, which will cool and fade over eons to come. Its stellar wind, streams of charged particles, rushes outward in opposite directions, like exhaust from back-to-back jet engines. This bipolarism, revealed by the Hubble Space Telescope, is common among planetary nebulae. Ultraviolet light from the star heats M2-9's gases and makes them glow.

Other types of nebulae exist in our galaxy, including dark nebulae rich in microscopic dust that blocks our view of stars beyond. When a star adjoins a dark nebula, the dust particles reflect starlight and the black cloud seems to have a silver lining.

8 The million-plus stars packed into a globular cluster such as Omega Centauri (right) are senior citizens of the Milky Way. Unlike human retirees, however, every star in the cluster is about the same age, billions of years older than our 4.6-billion-year-old sun.

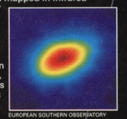


HUBBLE HERITAGE TEAM

PATRICK SEITZER, UNIVERSITY OF MICHIGAN

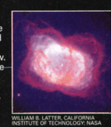
9 Peering between dust clouds toward the central bulge of the Milky Way, the Hubble Space Telescope focused on a rare clear region in the Sagittarius star cloud (above right). These Sagittarius stars formed at different times; most are older than the sun. They sparkle like an assortment of gems on a jeweler's velvet pad.

10 In some dark clouds lurk strange objects like G339.88-1.26, detected by a European Southern Observatory telescope in Chile and mapped in infrared light (right). A star 20 times as massive as the sun and 10,000 times brighter, it sports a disk of circumstellar dust, shown here in false color, about 20,000 times wider than Earth's orbit. Light from the hot star is absorbed by and warms the dust, making it glow.



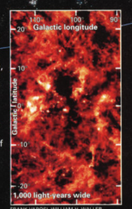
EUROPEAN SOUTHERN OBSERVATORY

11 As stars like the sun die, they become factories for interstellar dust. Celestial soot—the remnants of its red giant stage—surrounds the tiny hot central star of NGC 7027 (above right). Blown outward, the soot would obscure our view of the center of NGC 7027 were it not for this remarkable composite image in infrared and visible light from the Hubble Space Telescope.



WILLIAM B. LATTER, CALIFORNIA INSTITUTE OF TECHNOLOGY; NASA

Clouds of interstellar dust (right), strewn over huge regions along the central plane of the Milky Way, are not thick and smooth but seem as frothy as the head on a glass of beer. Supernova shock waves and stellar wind from evolving stars may have shaped this surprising pattern.



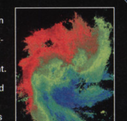
FRANK VAROSI, WILLIAM H. WALLER, NASA INFRARED ASTRONOMICAL SATELLITE; SKYVIEW

When a massive star comes to the end of its nuclear fuel supply, it collapses and then rebounds in a brief, powerful explosion, or supernova. The Chinese called these celestial fireworks guest stars and recorded one such event in the constellation Taurus in July 1054 that was visible in broad daylight.

JEFF HESTER, PAUL SCOWEN, ARIZONA STATE UNIVERSITY; NASA

12 In that location today astronomers find the fast-expanding Crab Nebula (left), a supernova remnant. At its heart lies a pulsar—a collapsed star—whirling 30 times a second.

Satellite galaxies of the Milky Way host equally remarkable celestial phenomena. In the Large Magellanic Cloud (above right), 180,000 light-years from Earth, clumpy, filamentary clouds of hydrogen gas reveal their stately march in a radio map from the Australia Telescope Compact Array. The lower half of the cloud (blue) is rotating toward the Earth while the topside (red) turns away.

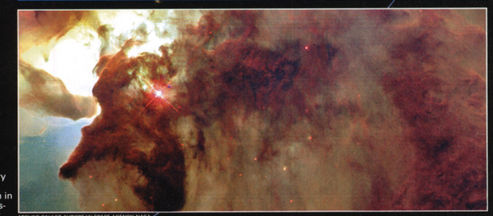


SUNGEUN KIM, UNIVERSITY OF ILLINOIS; LISTER STAVELEY-SMITH, ATNF

13 Glistening along the spiral arms of the galaxy, bright emission nebulae mark regions where new stars are forming. The Lagoon Nebula (above), about 5,000 light-years distant, is easily detected with the naked eye as a fuzzy spot in the southern constellation Sagittarius. Wide-field images show that it covers more of the sky than does the full moon. Where there was once only a vast dark cloud, radiation from the brightest and most massive young star in the nebula, Herschel 36, heats and ionizes the gas across a wide region. Despite the brilliance of the Lagoon Nebula and similar objects like the famous Orion Nebula, such areas are usually little more than hot blisters on the flanks of giant interstellar clouds.

With new tools, astronomers are unraveling the nature of the Milky Way and measuring distances to stars and nebulae with greater accuracy. Still, they ask, how did the Milky Way form in the first place? How and when did the arms form? How many more planets circle nearby stars besides the 20 already discovered? And the biggest question of all: Do any of them harbor life?

LAGOON NEBULA



ADELINE CAILLET, EUROPEAN SPACE AGENCY; NASA

Supplement to NATIONAL GEOGRAPHIC, October 1999

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MILLENNIUM IN MAPS

THE UNIVERSE

As far as we can see with our ever improving telescopes, there are at least a hundred billion galaxies arrayed throughout the universe. Each, like the Milky Way, is an "island universe" containing billions of stars. Nearly all galaxies are members of groups or clusters, which are part of even larger structures called superclusters. All of these large concentrations are connected by filaments or sheets of galaxies, which enclose huge, bubble-like volumes of empty space, the cosmic voids.

The great unifier of the cosmos is gravity. It holds the stars of a galaxy, and the galaxies of a cluster, together. But clusters, groups, and isolated individual galaxies are all flying away from each other, a continuing aftermath of the big bang, an explosion of space itself that astronomers believe formed the universe 11 to 15 billion years ago.

Produced by National Geographic Maps for National Geographic Magazine

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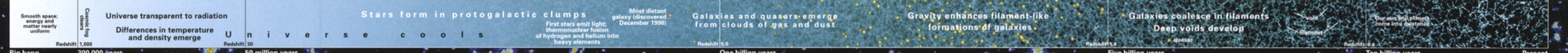
Washington, D.C., October 1999

EVOLUTION OF THE UNIVERSE

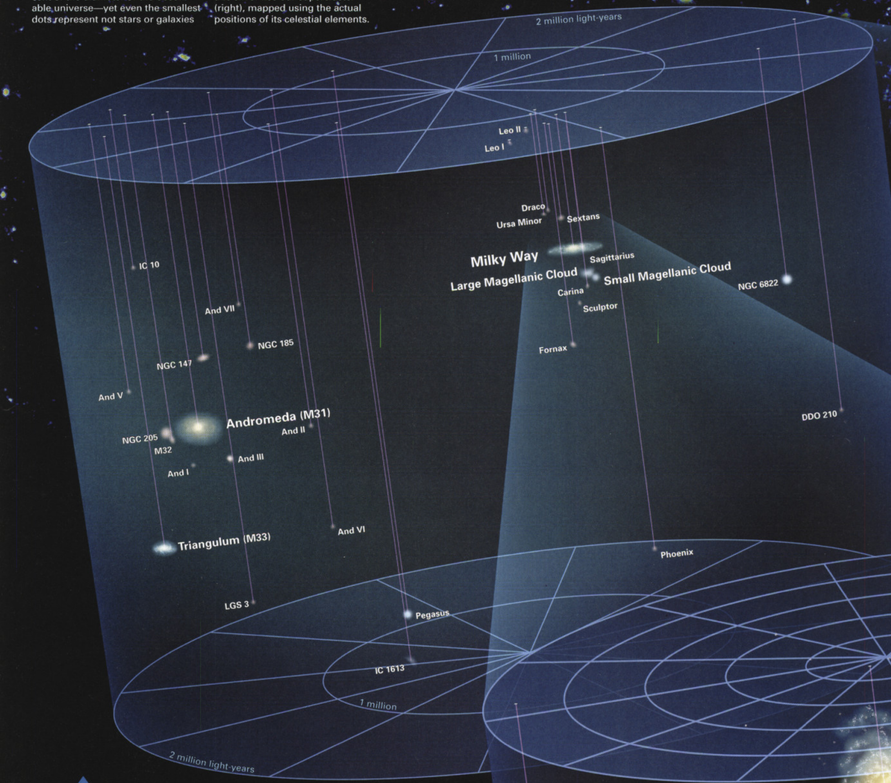
Combining evidence from microwave observations of deep space with supercomputer models, scientists have theorized about the structure of the universe from the big bang to the present (above). From the time that radiation and matter separated—300,000 years or so after the big bang—gravity began drawing matter first into clumps, then into stars. Perhaps a billion years later the first galaxies formed. As clusters of matter accumulated, the filament-and-void structure of today's universe unfolded.



Redshift—a measure of how far light from receding galaxies has been stretched to longer, or redder, wavelengths—marks cosmic distances.

1 SIZE OF THE UNIVERSE

So vast is space that just to find our solar system we must make five leaps of scale. In the background image on this sheet we see a mere sliver of the sky—roughly one percent of the diameter of the observable universe—yet even the smallest dots represent not stars or galaxies but great congregations of galaxies. Scattered clumps of dark matter and galaxies appear as bright colors in the image, which is based on a supercomputer simulation. Within this sliver lies our supercluster (right), mapped using the actual positions of its celestial elements.

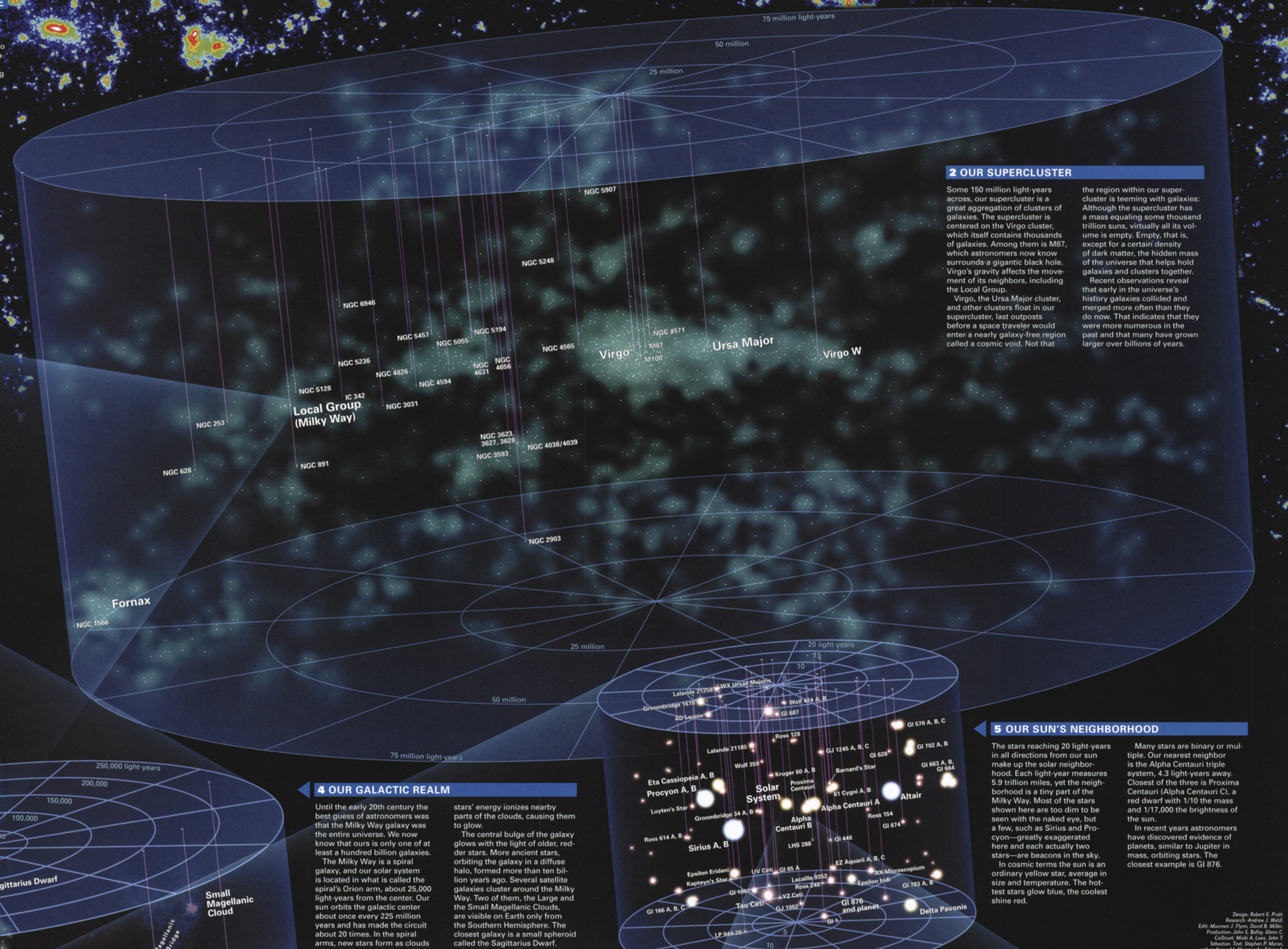


2 OUR SUPERCLUSTER

Some 150 million light-years across, our supercluster is a great aggregation of clusters of galaxies. The supercluster is centered on the Virgo cluster, which itself contains thousands of galaxies. Among them is M87, which astronomers now know surrounds a gigantic black hole. Virgo's gravity affects the movement of its neighbors, including the Local Group.

Virgo, the Ursa Major cluster, and other clusters float in our supercluster, last outposts before a space traveler would enter a nearly galaxy-free region called a cosmic void. Not that the region within our supercluster is teeming with galaxies: Although the supercluster has a mass equaling some thousand trillion suns, virtually all its volume is empty. Empty, that is, except for a certain density of dark matter, the hidden mass of the universe that helps hold galaxies and clusters together.

Recent observations reveal that early in the universe's history galaxies collided and merged more often than they do now. That indicates that they were more numerous in the past and that many have grown larger over billions of years.



3 THE LOCAL GROUP

Galaxies stretch in every direction beyond the Milky Way, but gravity keeps a family of some 30 galaxies, including our own, loosely bound.

This Local Group of galaxies extends some four million light-years across. Most galaxies in the group are considered dwarfs, but the two largest—our own Milky Way and the Andromeda galaxy—are giant spirals. Andromeda is at the center of a small subgroup, which includes two elliptical galaxies, M32 and NGC 205, where star formation has ceased. Even though it is more than two million light-years away from Earth, the Andromeda galaxy can be seen readily with the naked eye. With even a small telescope, its bright bulge is unmistakable.

It is possible that astronomers have not found some of our group's smaller galaxies, which may be hidden behind dust clouds in the Milky Way.

All three main types of galaxies are represented in the Local Group: spirals, ellipticals, and irregulars. Nevertheless, the group has relatively few members, a hundredth that of some large galaxy clusters.

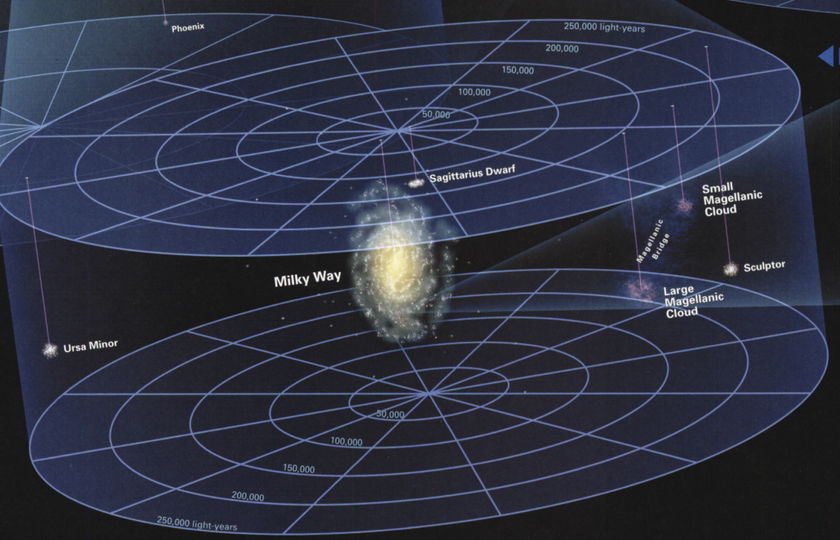
The galaxies of the Local Group are traveling together through space. Measurements show that the Milky Way is falling toward Andromeda. No collision is expected, however: Like race cars on opposite straightaways, the two are most likely at opposite ends of a highly elongated orbit around the group's center of mass.

4 OUR GALACTIC REALM

Until the early 20th century the best guess of astronomers was that the Milky Way galaxy was the entire universe. We now know that ours is only one of at least a hundred billion galaxies.

The Milky Way is a spiral galaxy, and our solar system is located in what is called the spiral's Orion arm, about 25,000 light-years from the center. Our sun orbits the galactic center about once every 225 million years and has made the circuit about 20 times. In the spiral arms, new stars form as clouds of gas and dust condense. The stars' energy ionizes nearby parts of the clouds, causing them to glow.

The central bulge of the galaxy glows with the light of older, redder stars. More ancient stars, orbiting the galaxy in a diffuse halo, formed more than ten billion years ago. Several satellite galaxies cluster around the Milky Way. Two of them, the Large and the Small Magellanic Clouds, are visible on Earth only from the Southern Hemisphere. The closest galaxy is a small spheroid called the Sagittarius Dwarf.



5 OUR SUN'S NEIGHBORHOOD

The stars reaching 20 light-years in all directions from our sun make up the solar neighborhood. Each light-year measures 5.9 trillion miles, yet the neighborhood is a tiny part of the Milky Way. Most of the stars shown here are too dim to be seen with the naked eye, but a few, such as Sirius and Procyon—greatly exaggerated here and each actually two stars—are beacons in the sky.

In cosmic terms the sun is an ordinary yellow star, average in size and temperature. The hottest stars glow blue, the coolest shine red.

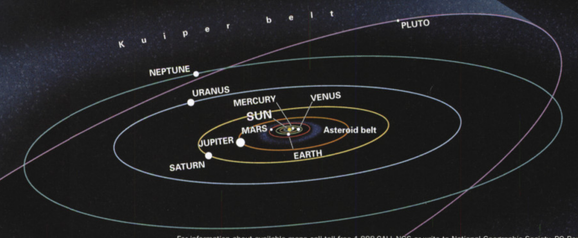
Many are binary or multiple. Our nearest neighbor is the Alpha Centauri triple system, 4.3 light-years away. Closest of the three is Proxima Centauri (Alpha Centauri C), a red dwarf with 1/10 the mass and 1/17,000 the brightness of the sun.

In recent years astronomers have discovered evidence of planets, similar to Jupiter in mass, orbiting stars. The closest example is Gl 876.

6 OUR SOLAR SYSTEM

A tiny dot on the scale of the universe, the solar system—our home in the galaxy—measures some 4.6 billion miles from the sun to the farthest extent of Pluto's orbit. Sunlight reaches Earth in about 8 minutes and Jupiter in 43 minutes, but it takes nearly 7 hours to pass the orbit of Pluto.

Beyond Neptune are icy bodies smaller than planets. These are Kuiper belt objects, over a hundred of which have been observed by telescope. Some scientists suggest that Pluto is a Kuiper belt object, rather than a planet. Spread in a great sphere around the entire solar system is the Oort cloud, trillions of comets, a few of which make spectacular visits to the sun.



Planetary alignment, January 1, 2000

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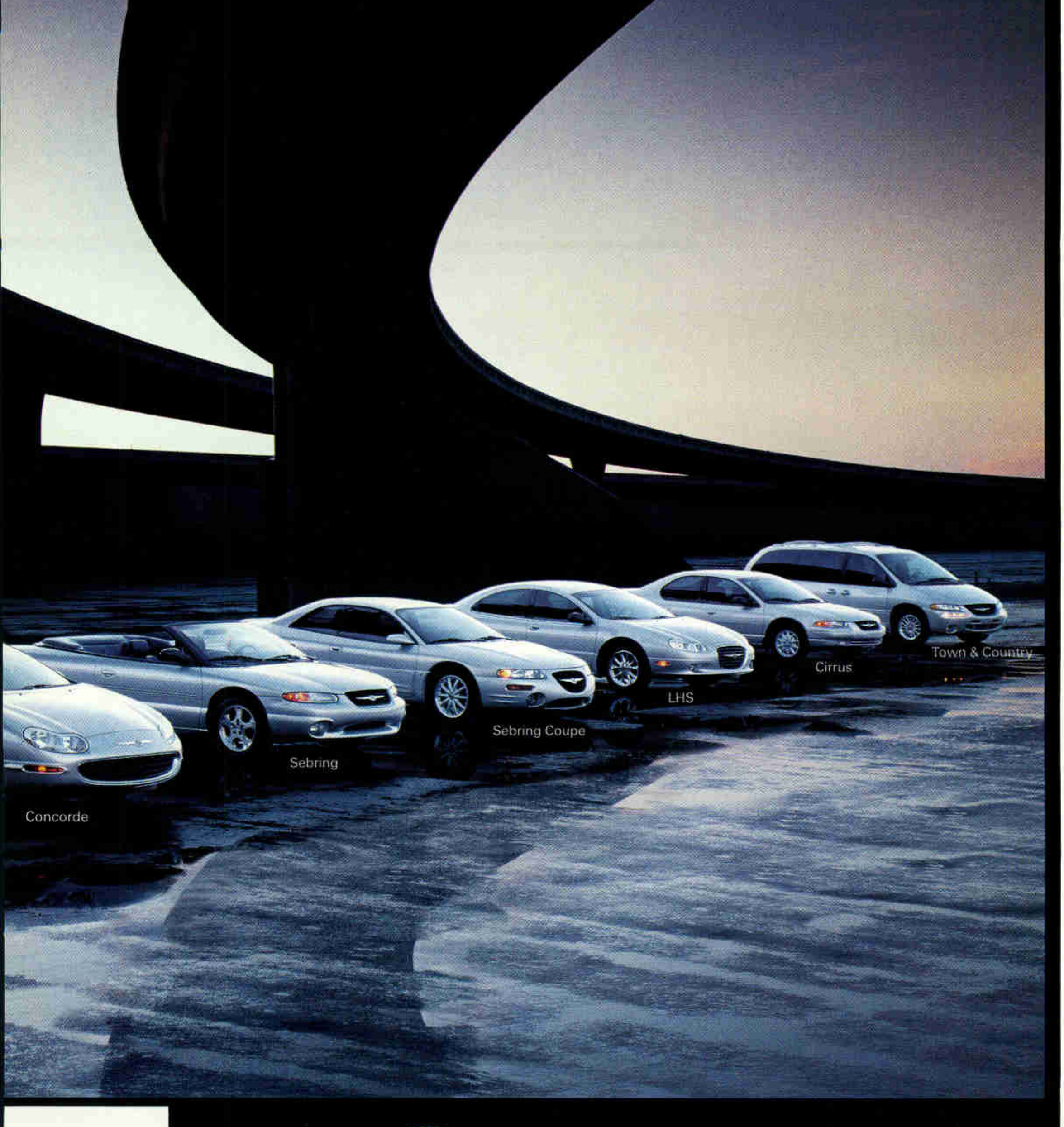

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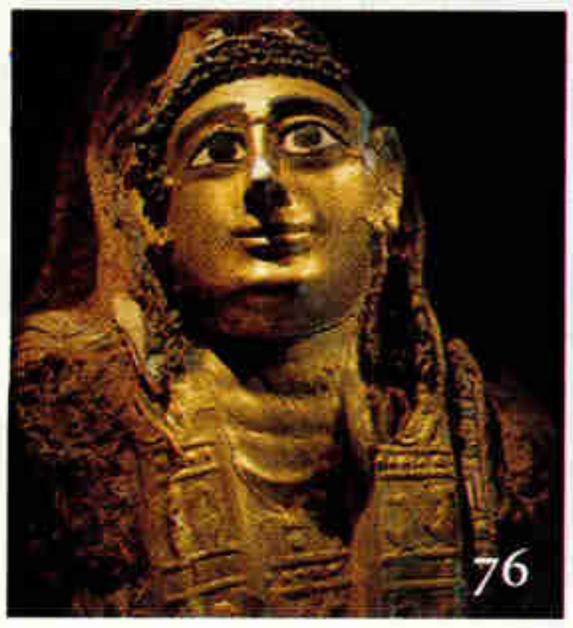

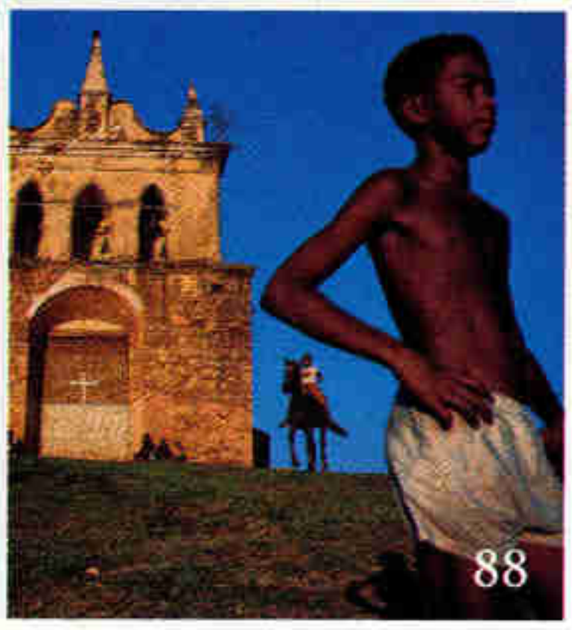

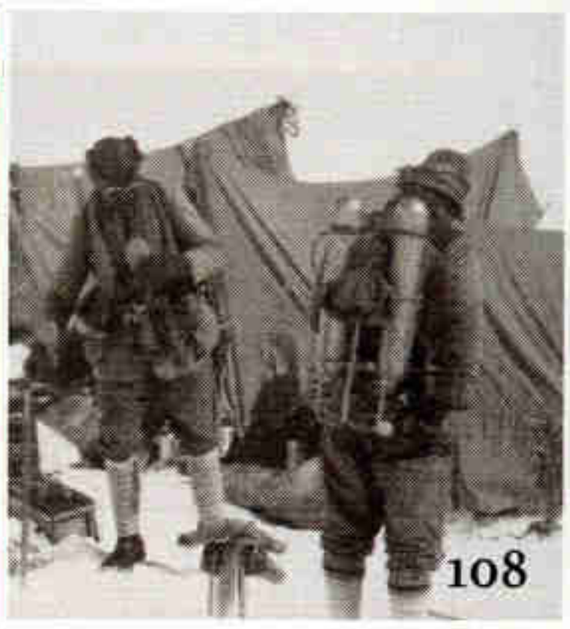

2 **Science—Asking Infinite Questions** *From the matter that makes up the universe to the strands of DNA that make us who we are, scientists are steadily unlocking the secrets of the ages.*
BY JOEL L. SWERDLOW

■ *Millennium Supplement: The Universe*

8 **Unveiling the Universe** *Astronomers claim the universe itself as their laboratory. Their subjects: black holes, exploding stars, and alien worlds that could harbor intelligent life.*
BY KATHY SAWYER PHOTOGRAPHS BY JOE McNALLY

42 **Secrets of the Gene** *As scientists race to crack the code of human life, breakthroughs in genetic research are yielding powerful new tools that hold shining promise and raise unsettling questions.*
BY JAMES SHREEVE PHOTOGRAPHS BY KAREN KASMAUSKI

76 **Valley of the Mummies** *Archaeologists at an Egyptian oasis have uncovered a vast burial site containing gilded mummies and stunning artifacts from a world that vanished nearly 1,700 years ago.*
BY DONOVAN WEBSTER PHOTOGRAPHS BY KENNETH GARRETT

88 **Cuba's Colonial Treasure** *Rich in 18th-century architecture, the small town of Trinidad has been acclaimed a World Heritage site.*
BY A. R. WILLIAMS PHOTOGRAPHS BY DAVID ALAN HARVEY

108 **George Mallory** *This spring the author found the body of the British mountaineer who disappeared 75 years ago while climbing Mount Everest. Was Mallory the first man to reach the summit?*
BY CONRAD ANKER

114 **The Last Dive** *In 1944 the Japanese submarine* I-52 *made a fatal attempt to deliver precious cargo—including two tons of gold bound for the Japanese Embassy in Berlin. Three miles deep in the Atlantic, the wreck of the submarine yields a wealth of memories but no gold.*
BY PRIIT J. VESILIND PHOTOGRAPHS BY JONATHAN BLAIR

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The Cover

A creation of genetic engineering, this piglet has been bred to carry the human DNA needed to produce factor VIII, a blood-clotting protein. Photograph by Karen Kasmauski

Cover printed on recycled-content paper

NATIONAL GEOGRAPHIC

Breaking News

Dinosaurs for the New Millennium

Dramatic finds from fossil beds in Liaoning Province, China, reveal that many theropods, or meat-eating dinosaurs—a group that includes *Tyrannosaurus rex*—bore feathers at some stage in life. Among the newly discovered creatures is *Sinornithosaurus millenii,* or "Chinese bird-reptile of the millennium" (above). With long flapping arms and a coat of feathers *Sinornithosaurus* is the closest yet that a dinosaur has come to being a bird. But it is not a bird; it belongs to the family of theropods known as dromaeosaurs—sharp-clawed predators that include the "raptors" of *Jurassic Park* fame. Adding dromaeosaurs to the list of feathered theropods puts another link in the evolutionary chain from dinosaurs to birds.

NATIONAL GEOGRAPHIC has worked closely with the paleontologists in preparation for the announcement of these discoveries. In a forthcoming issue we will present a comprehensive coverage of *Sinornithosaurus* and the other new finds that will forever change the way you view dinosaurs.

For more details, visit our website: *www.nationalgeographic.com/news*

MODEL BY BRIAN COOLEY; PHOTOGRAPH BY O. LOUIS MAZZATENTA

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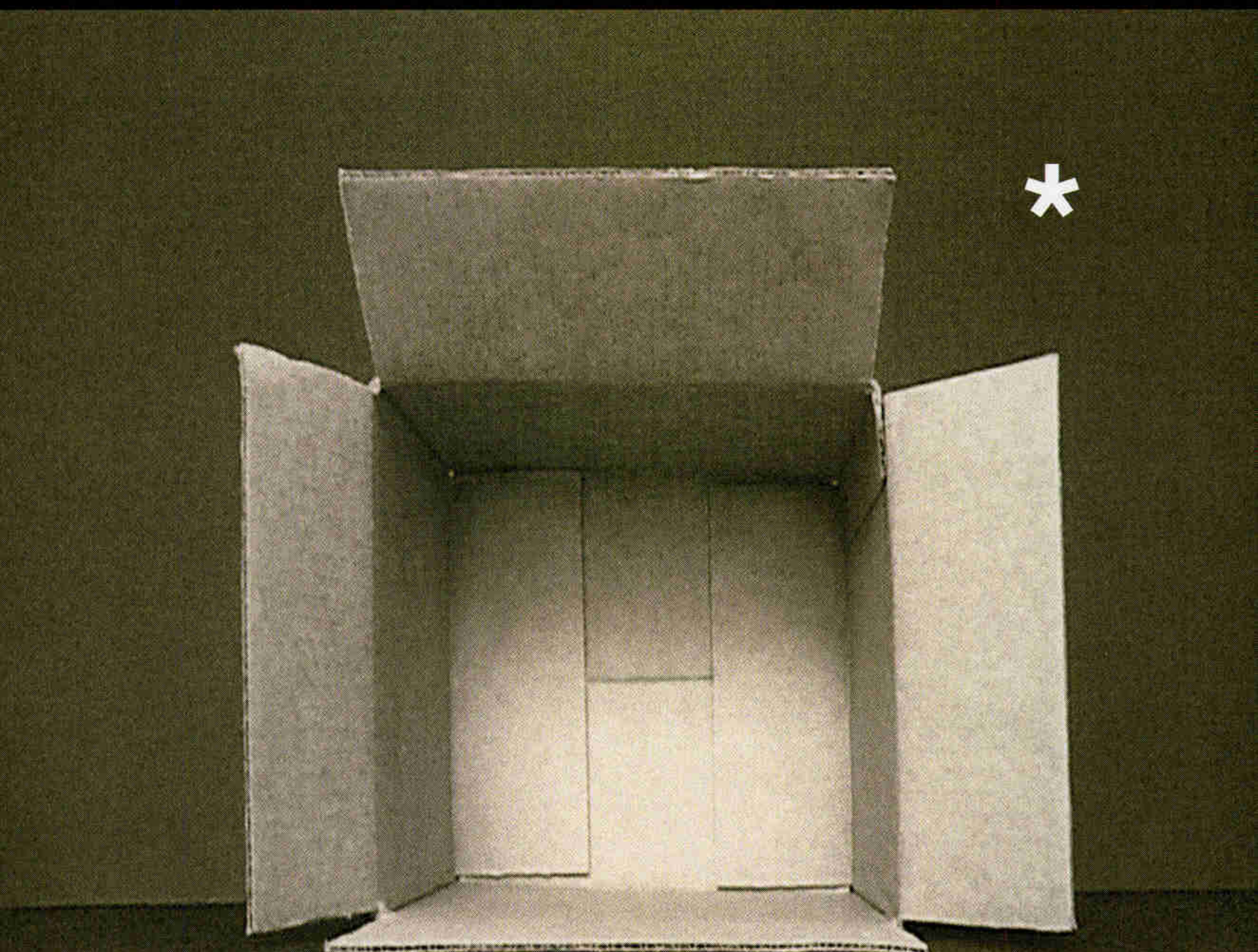

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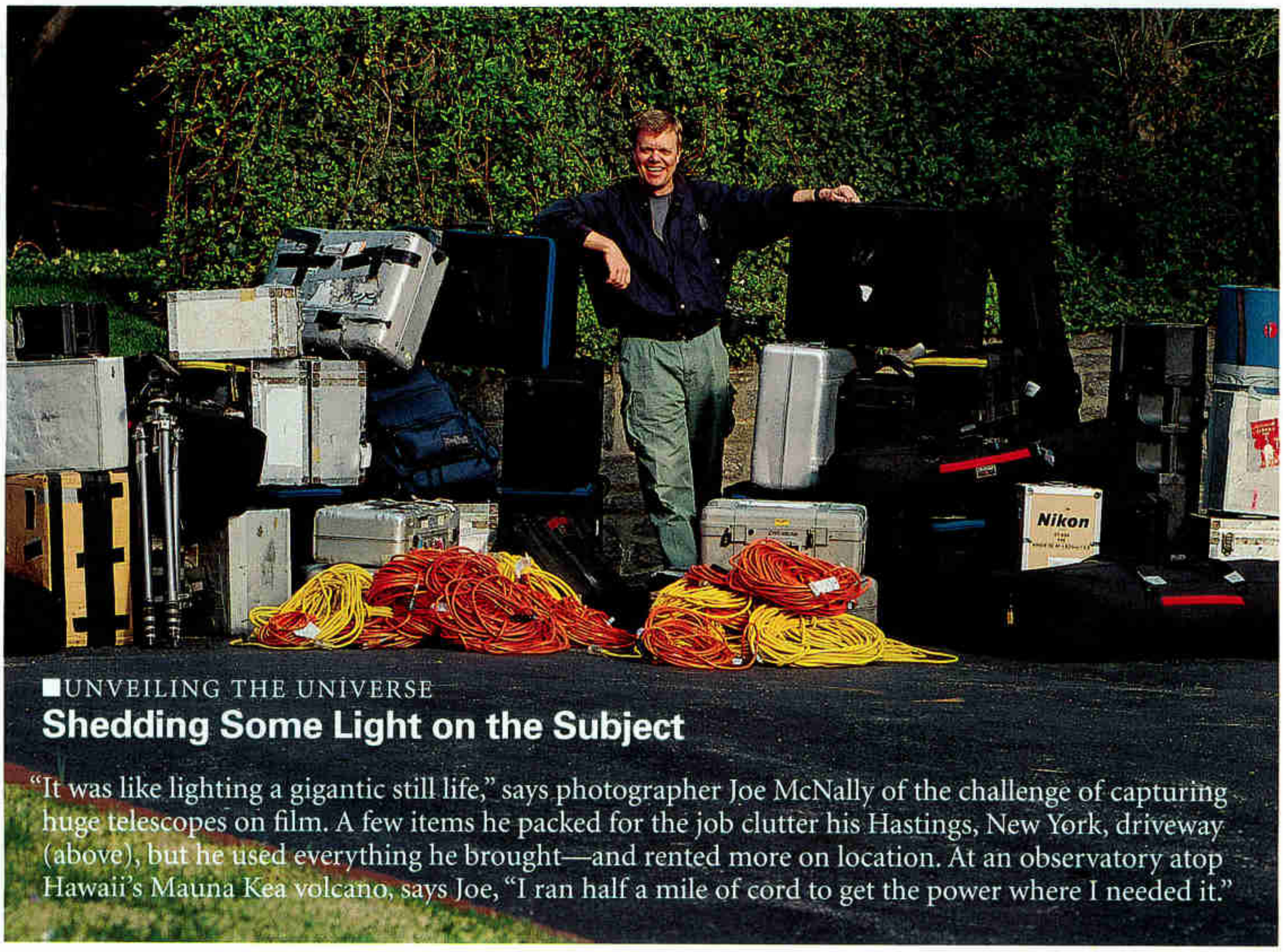
On Assignment



■ UNVEILING THE UNIVERSE

Shedding Some Light on the Subject

"It was like lighting a gigantic still life," says photographer Joe McNally of the challenge of capturing huge telescopes on film. A few items he packed for the job clutter his Hastings, New York, driveway (above), but he used everything he brought—and rented more on location. At an observatory atop Hawaii's Mauna Kea volcano, says Joe, "I ran half a mile of cord to get the power where I needed it."

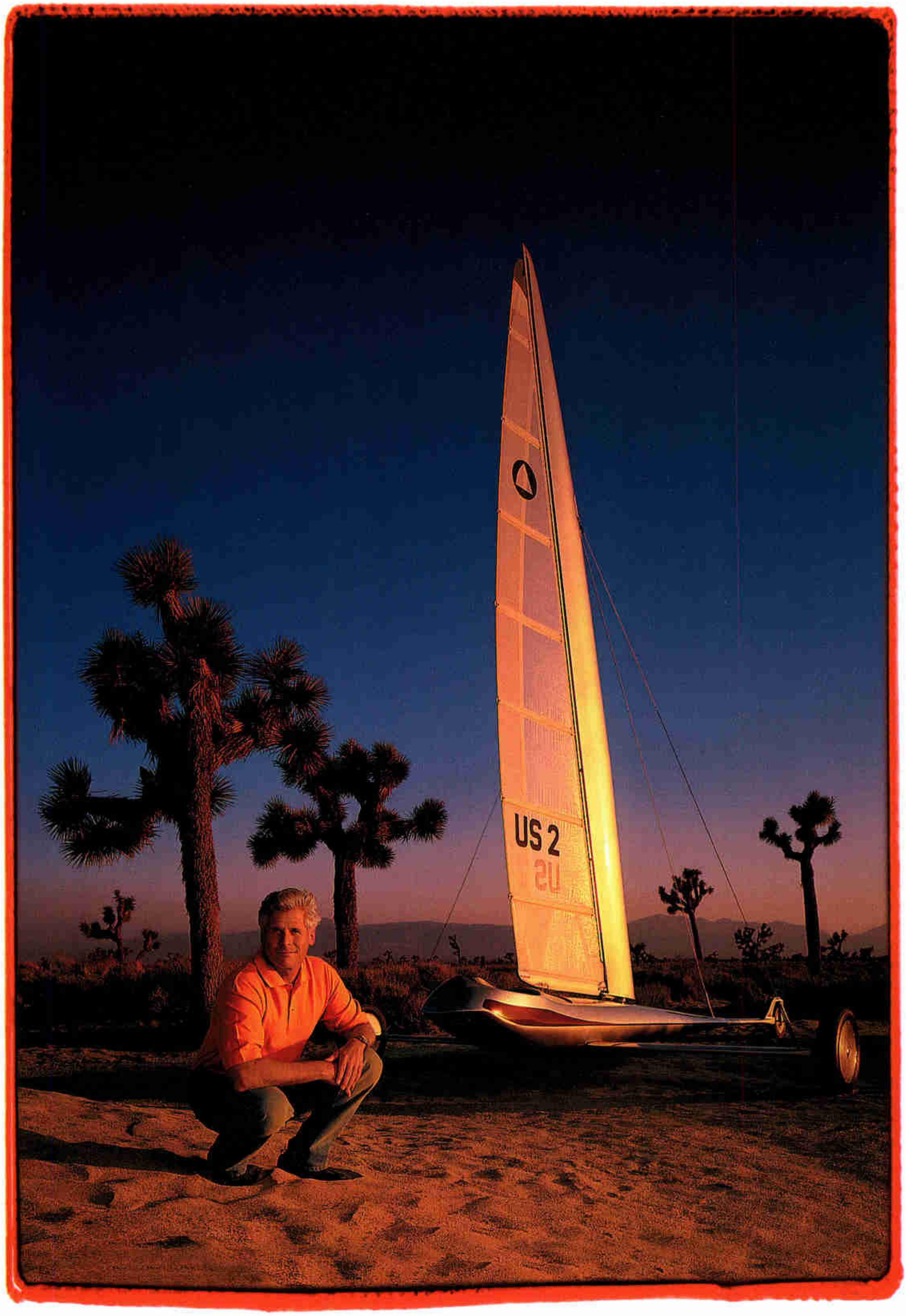
■ LAST DIVE OF THE *I-52*

That Sinking Sensation

He knew he was going down; Priit Vesilind just didn't know how low things could go. Shown climbing aboard the Russian *Mir 1* submersible in search of gold spilled from the wreck of the *I-52*, the senior writer (right) spent the next 16 hours in *Mir 1*'s cramped interior, unable to move from a reclining position. He took photographs, scribbled notes, and peered through a tiny window to record the relative positions of objects—none of them treasure—on the ocean floor. The submersible's two crew members spoke little English and weren't inclined to be communicative, although when the *Mir 1* appeared stalled at the bottom of the sea, Priit's pictogram queries about gaining buoyancy did bring reassurances. "But for a while," says Priit, "it wasn't much fun waiting."

Priit finally surfaced safely, only to face more danger: the daily volleyball game on the deck of the mother ship, *Keldysh*. In one game he injured an ankle tendon and returned to Society headquarters with a limp.

NINA SABO (TOP); JONATHAN BLAIR



PEOPLE IN SOUTHERN CALIFORNIA

are always looking

FOR RADICAL NEW WAYS TO GET AROUND

If it's new and it's got wheels, chances are it came from Southern California. People here aren't just content to walk; they'd rather pedal, skate or scoot.

Maybe it's great weather that inspires Southern Californians to design so many ways to get out and about. Or maybe it's the wide-open spaces. Whatever it is, innovation is no stranger to the roads and pathways of this beautiful corner of the world.

The Prius hybrid vehicle

Toyota's design center, CA

It's probably no coincidence, then, that the design for the world's first mass-produced hybrid vehicle was developed in Southern California. In Newport Beach, to be precise, at Toyota's futuristic North American design center, known as Calty.

Here, a team of designers created the look that is already turning heads overseas for Toyota's breakthrough alternative fuel vehicle, the Prius.

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NATIONAL GEOGRAPHIC'S

Millennium Moments

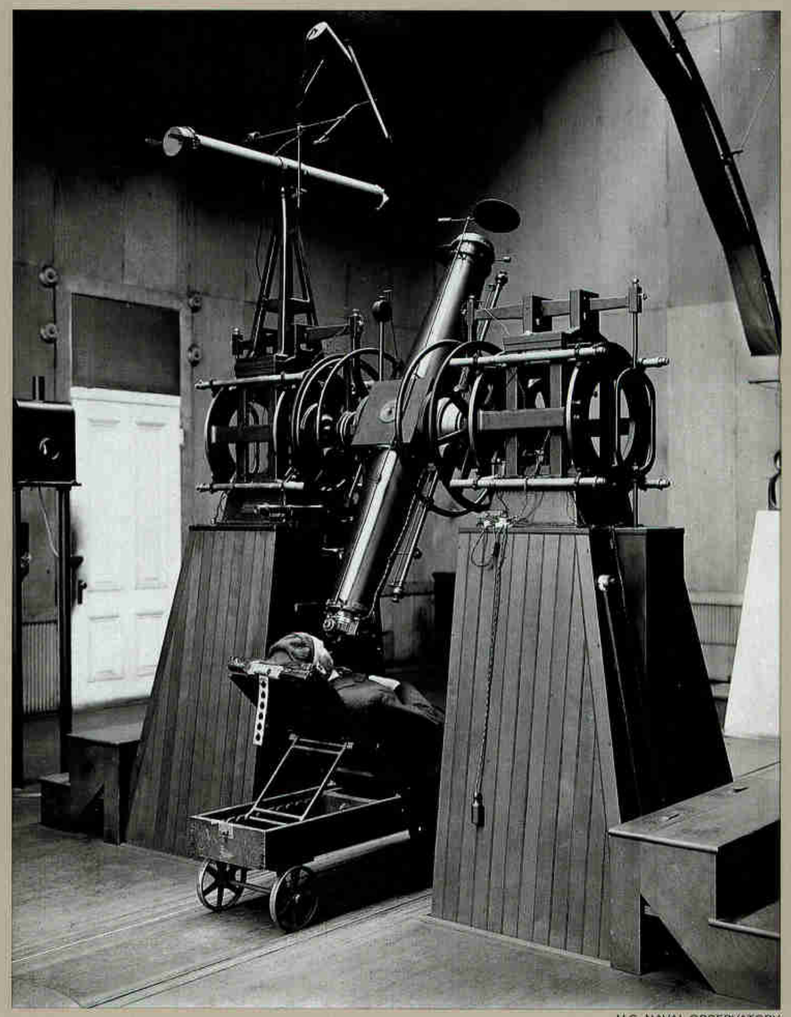
The Geographic's Eyes on Science

On May 27, 1900, Alexander Graham Bell, Gilbert H. Grosvenor—later the magazine's Editor—and other Society members took a steamboat from Washington, D.C., to Norfolk, Virginia, to view a total solar eclipse. "The ladies all got out and spread white sheets over the dock," Grosvenor recalled, "to watch the shadow of the moon as it traversed over these sheets."

The Society's fascination with such phenomena was echoed by the man in the street. "America has become a nation of science," observed W J McGee, one of the GEOGRAPHIC's earliest editors, in 1898. The magazine presented some pure science by paleontologists and archaeologists who pushed back the evolutionary clock with fossil finds. But more often science articles were a by-product of Society-funded expeditions: the polar assaults of Peary and Byrd or the scaling of Mount Everest. Bathyspheres plumbed ocean depths, while ever higher balloon flights challenged atmospheric physics.

The Society's most far-reaching quests came from scientists who lifted their eyes beyond Earth. Powerful new telescopes whetted our stellar appetite. A 1925 article, "Interviewing the Stars," speculated about canals on Mars, huge, distant nebulae—"the breeding ground where stars are born"—and about other possible inhabited universes. "Astronomy offers more thrills to the alert human mind than all the fiction in the Library of Congress!"

With the advent of manned spaceflight the GEOGRAPHIC undertook near-saturation coverage, from the Project Mercury missions in the 1960s to a five-part package on the 1969 Apollo 11 lunar landing to the space shuttle. Last June the magazine came full circle with an article on John Glenn's return to space to help study aging.

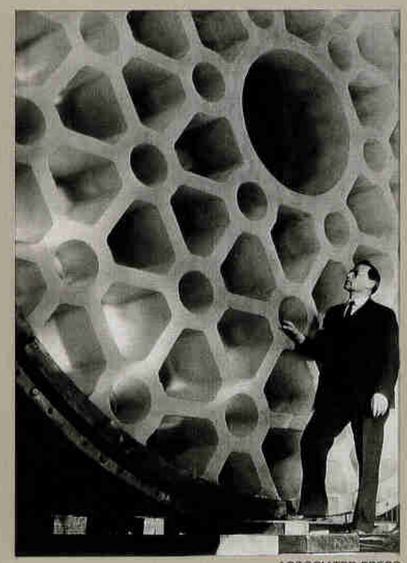


U.S. NAVAL OBSERVATORY

AN ANTIQUE THAT KEEPS ON TICKING
A six-inch transit circle telescope installed in 1898 is still operating at the U.S. Naval Observatory in Washington, D.C., after recording more than a million star positions. The telescope, now used only occasionally, measures a star's position when it crosses, or transits, the instrument's crosshairs. This helped the observatory fulfill a major mandate—to accurately measure time. This photograph, received by the Society in 1931, has never been published in the GEOGRAPHIC.

MOUNT WILSON AND PALOMAR OBSERVATORIES

J. BAYLOR ROBERTS



ASSOCIATED PRESS

GEOGRAPHIC HELPS MAP THE HEAVENS IN SKY SURVEY
"Most extensive map ever conceived by the mind of man," said an astronomer of the 1949-1956 National Geographic Society-Palomar Observatory Sky Survey. Its objective: to photograph the entire visible sky with the 48-inch Big Schmidt telescope on California's Palomar Mountain. One of the survey's 1,758 photographic plates shows part of Sagittarius, a constellation in the Milky Way (top). The project "has spread out the celestial sphere like a huge treasure chart," wrote George O. Abell, a survey official. It covered at least 25 times as much area as any previous celestial study and located millions of new galaxies and stars.

The stars circling Polaris, the North Star (above left), were recorded overhead of the Big Schmidt's dome, visible at lower right, when a photographer kept his shutter open for seven hours, creating a time exposure. Used in tandem during the Sky Survey was a second telescope on Palomar, the 200-inch Hale; a 1939 GEOGRAPHIC article showed its mirror (above right) while the Hale was still under construction. The Big Schmidt acted like a huge wide-angle lens. The Hale saw a much narrower area but was three times as powerful, penetrating a billion light-years of space. The Big Schmidt explored, then the Hale zoomed in.

Scientific Milestones

■ **A.D. 1400-1500**
Modern science begins during the Renaissance in Europe, sparked by ancient texts—Euclid's geometry, Ptolemy's geography, Galen's medicine—that were preserved through the Dark Ages by Arab scholars.

■ **1500-1600**
In 1543 Vesalius publishes the first accurate human anatomy, and Copernicus theorizes that the Earth and other planets revolve around the sun.

In 1572 Brahe's observations of a supernova prove that celestial bodies are not unchanging.

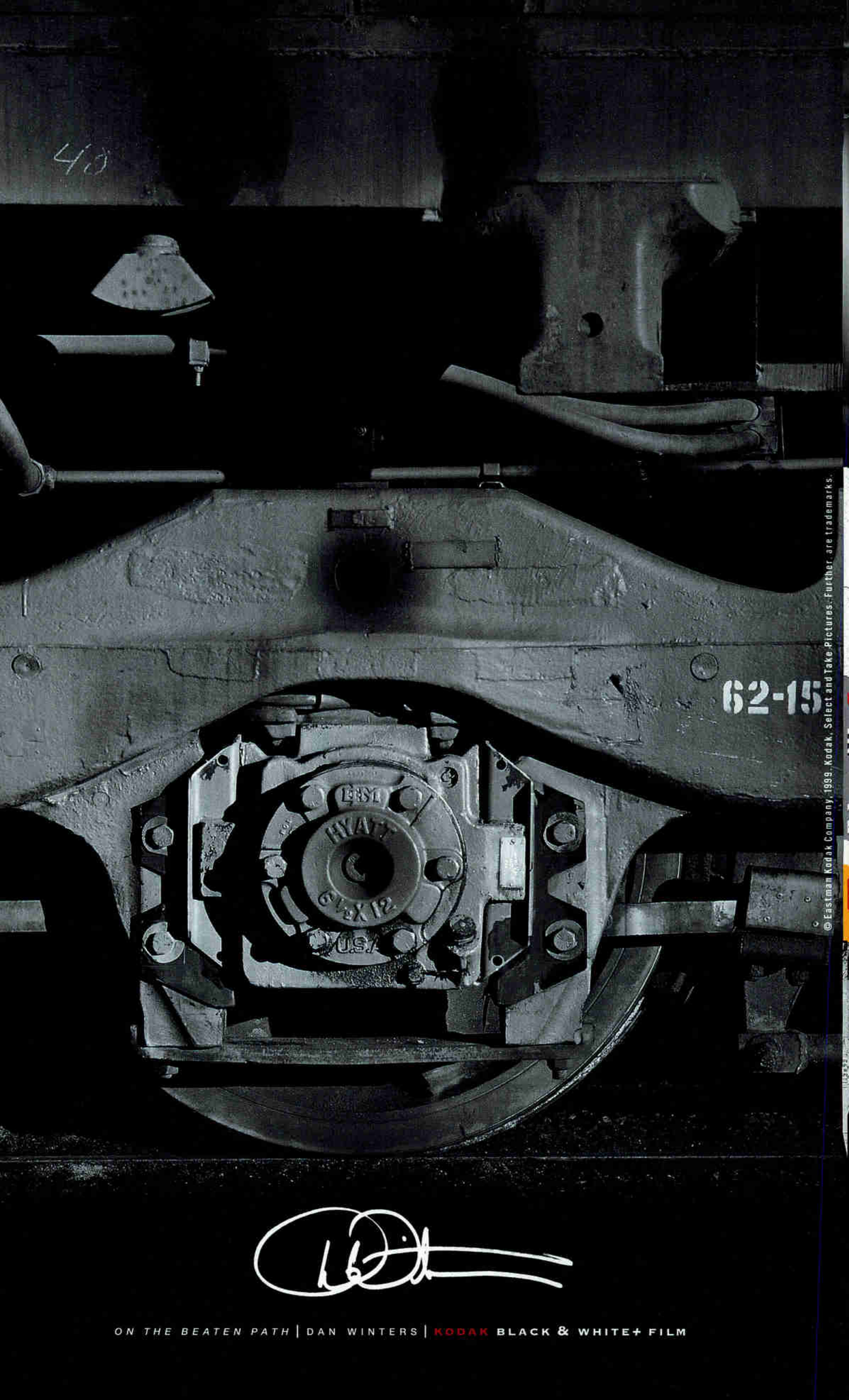
■ **1600-1700**
Galileo uses the newly invented telescope to see the moon's craters in 1609 and satellites of Jupiter in 1610.

Kepler sets out laws of planetary motion in 1609.

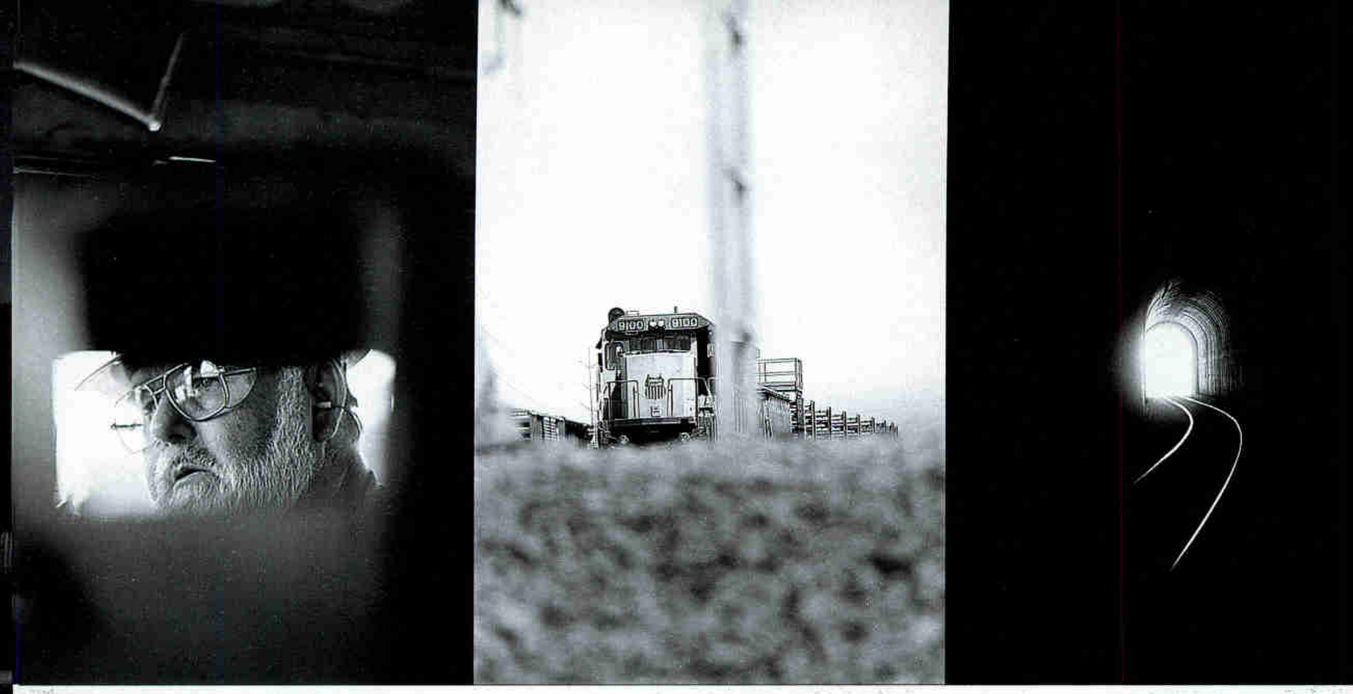
Napier invents logarithms in 1614, facilitating numerical computations.

In 1628 Harvey describes the circulation of blood.

Newton's 1687 laws of gravity and motion join earthly and celestial dynamics in one common scheme. His theory of optics comes out in 1704.



ON THE BEATEN PATH | DAN WINTERS | KODAK BLACK & WHITE+ FILM



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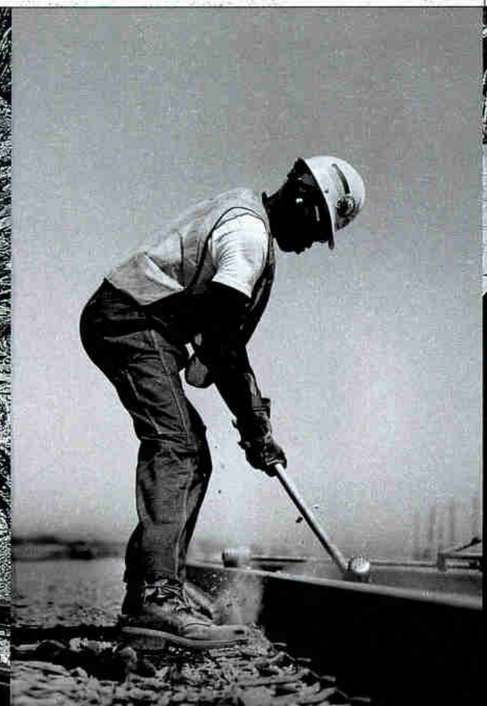
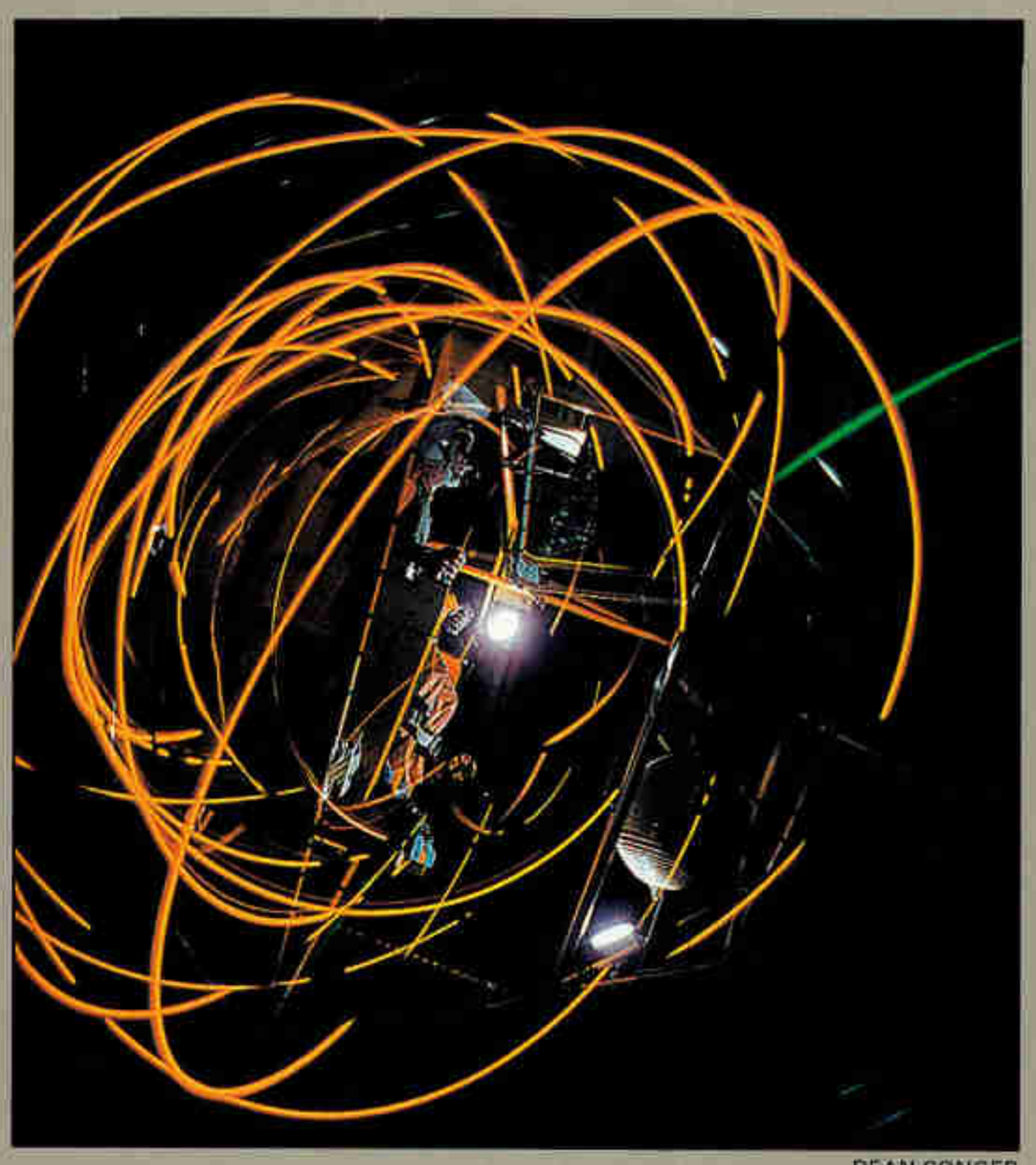


LUIS MARDEN



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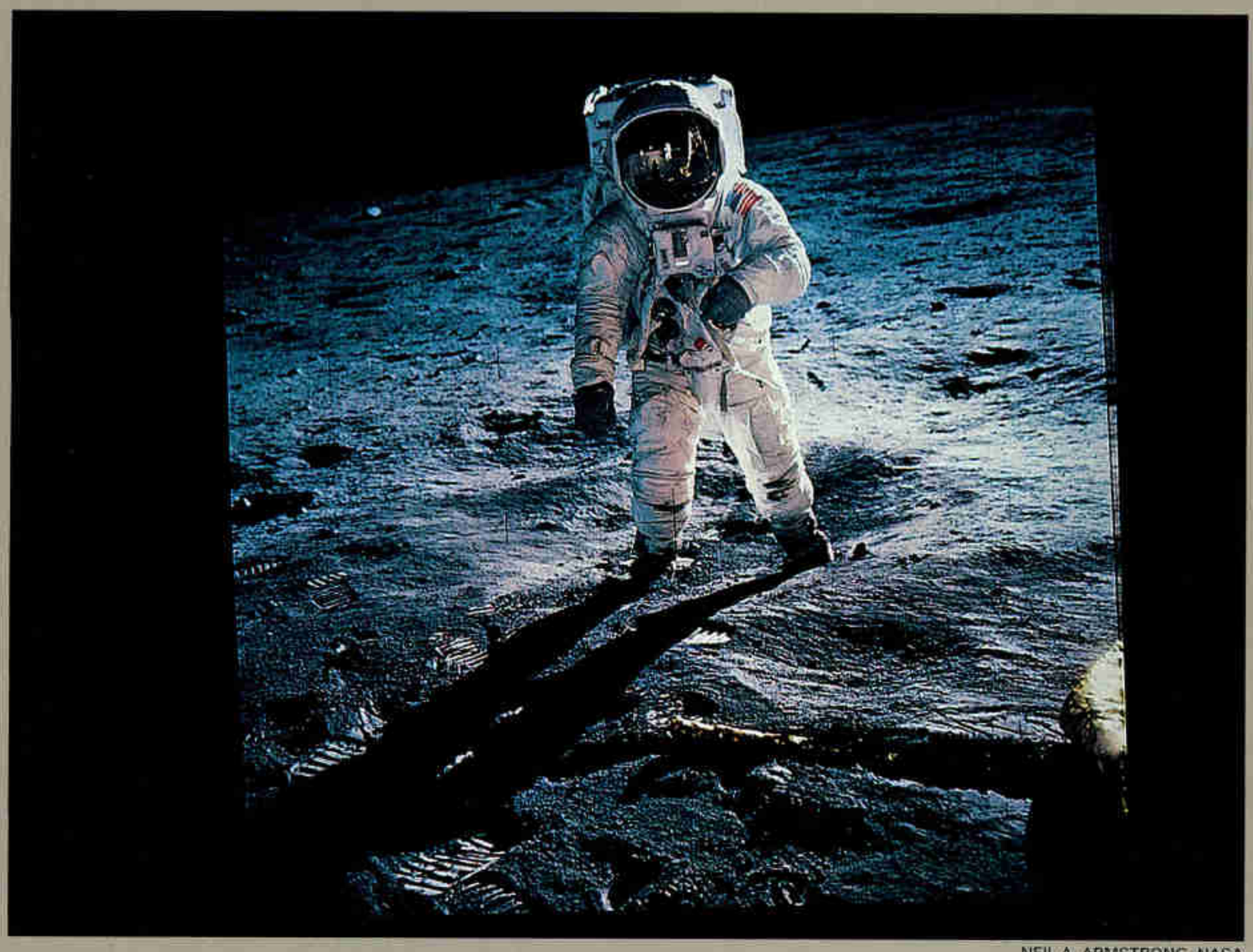

NEIL A. ARMSTRONG, NASA

KEEPING PACE ON THE LONG ROAD TO THE MOON

Nearly as famous as the words uttered on the moon by astronaut Neil Armstrong—"That's one small step for a man, one giant leap for mankind"—was the photograph he took of Edwin "Buzz" Aldrin, which ran on the GEOGRAPHIC'S December 1969 cover. The Apollo 11 mission "was the coming of age of the space program, for it was the 21st manned spaceflight for the United States," wrote Kenneth F. Weaver in that issue's 62 pages of coverage. Dozens of spaceflight articles were published, some on training, research, and testing during the "what if" era before the first manned Mercury missions of the early 1960s. What if an astronaut's capsule, returning from space into Earth's atmosphere, was buffeted out of control? At Lewis Space Center in Cleveland, Ohio, a "jet-powered whirligig" (top right) simulates such problems in a July 1960 story. The spinning test pilot regains control by using gas jets. His wild ride is outlined by lights on the chair's tubular framework. In 1955 Heinz Haber of the University of California examines a model of a four-stage, 180-foot-tall rocket; he holds a capsule that would allow a crewman outside the ship—a gleam in the eye of later designers.

Leeuwenhoek discovers microorganisms in 1674.

■ **1700-1800**

Systema Naturae, published by Linnaeus in 1735, establishes his system for classifying and naming organisms.

Franklin shows that lightning is electricity in 1752 by flying a kite connected to a key.

Priestley describes "dephlogisticated air" in 1774. It is renamed oxygen five years later by Lavoisier, father of quantitative chemistry.

In 1781 Herschel discovers Uranus, the first new planet since prehistory.

Scientific geology begins in 1795 with Hutton's *Theory of the Earth.*

Jenner vaccinates against smallpox in 1798.

■ **1800-1900**

Study of electricity and magnetism advances rapidly after Volta invents the electric battery, the first source of current electricity, in 1800. Ørsted connects electricity with magnetism in 1820, and in 1831 Faraday demonstrates electromagnetic induction.

Dalton sets out an atomic theory of matter in 1808.

A table of relative atomic weights is published by Berzelius in 1818.

In 1857 Pasteur reports that microorganisms cause fermentation; his work leads to the pasteurization of food.

In 1859 spectroscopy reveals the chemical composition of the stars.

Also in that year Darwin publishes *The Origin of Species.* Mendel's genetic laws of heredity come out in 1865 but are not included in evolution theory until 1900.

In 1864 Maxwell's equations describe electromagnetism.

The periodic table of elements is published by Mendeleyev in 1871.

Röntgen discovers x-rays in 1895, and rays emitted by natural elements—uranium, thorium, radium—are observed by Becquerel in 1896 and the Curies in 1898.

■ **1900-present**

From 1900 to1920 theoretical physics rethinks the microworld, adopting quantum mechanics.

Rutherford introduces the nuclear atom in 1911.

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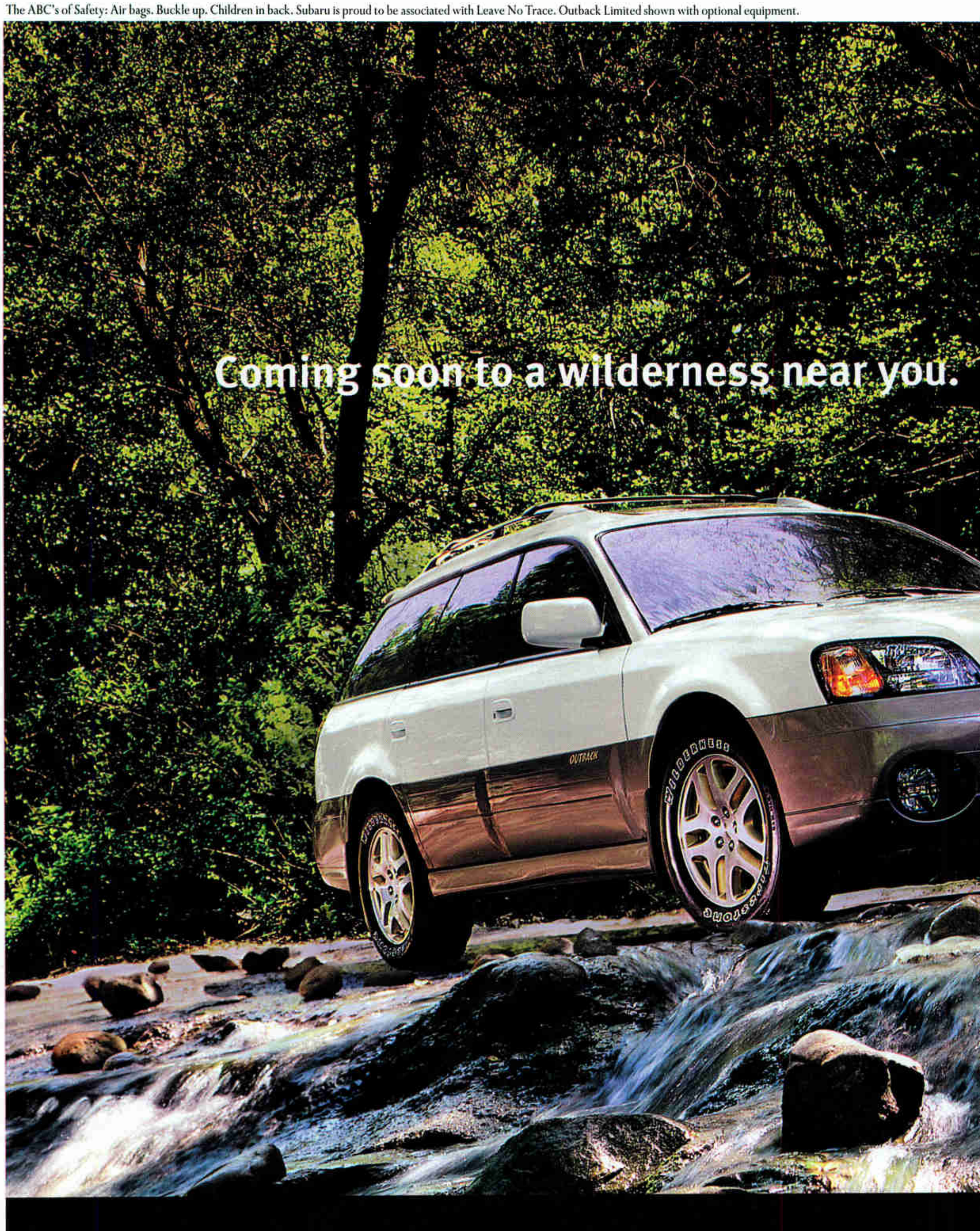

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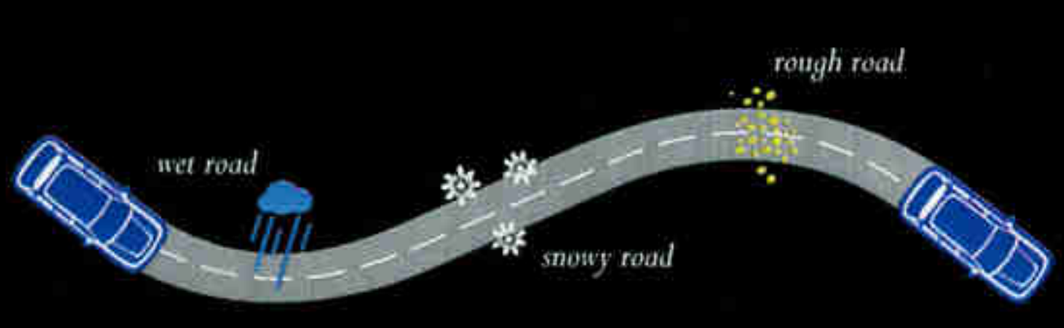

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Einstein's theories of relativity appear in 1905 and 1916.

In 1918 Shapley pictures the sun as a marginal star in a vast Milky Way. Hubble realizes in 1929 that galaxies recede from one another in an expanding universe, and Russell shows that deep space contains mainly hydrogen, the fuel of the stars. In 1932 Jansky detects radio emissions from cosmic sources.

World War II stimulates an array of inventions, notably the nuclear reactor, first put in service in 1942, and the general-purpose digital computer, first used in 1945. In 1948 the transistor, precursor of the computer chip, makes computers commercially feasible.

The double helix structure of the DNA molecule is discovered in 1953 by Watson and Crick.

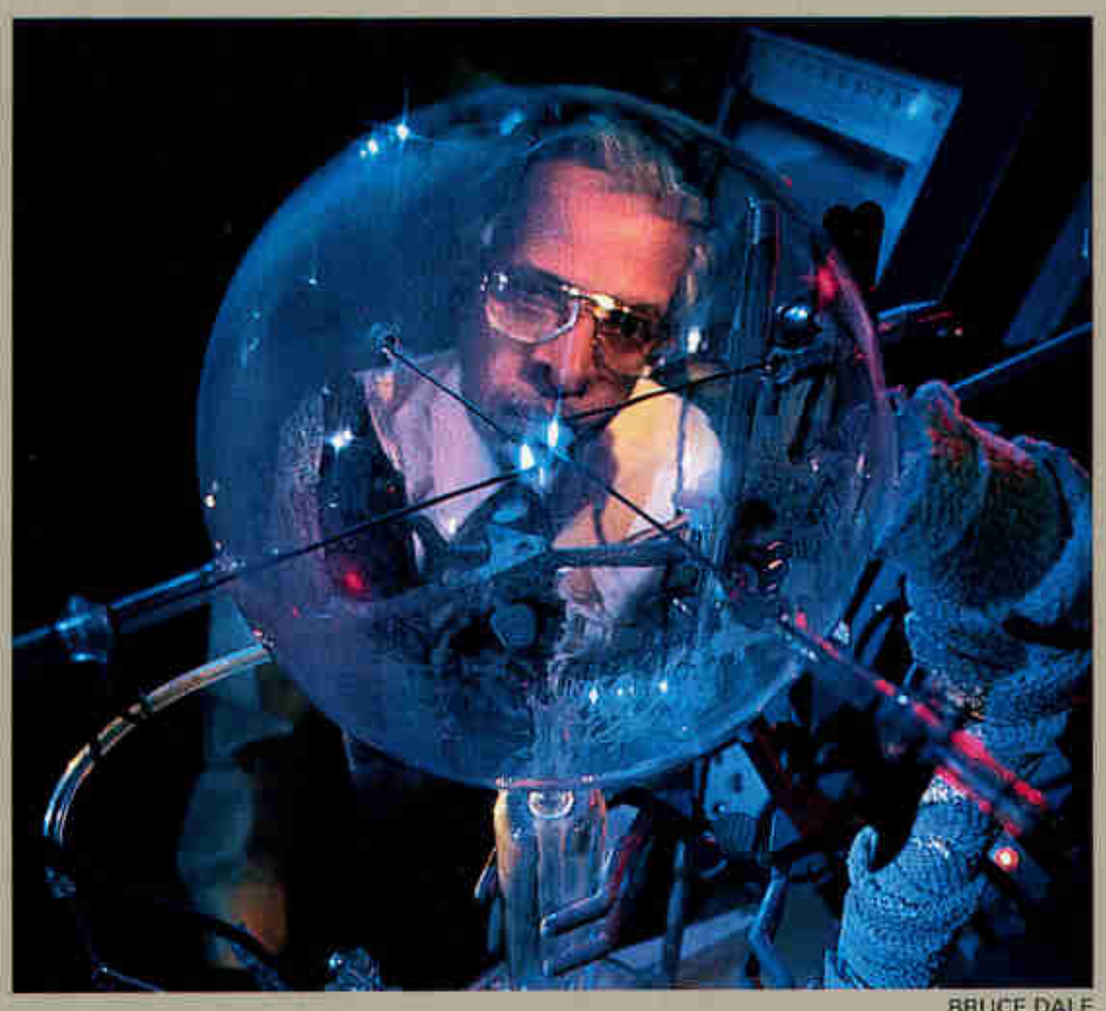
Sputnik 1 and *2*, Earth's first artificial satellites, are launched in 1957.

In 1960 the first gas-discharge laser is built.

Continental drift, proposed but ignored in 1912, forms the basis of plate tectonics, the theory that enlivens geology in the 1960s.

In July 1969 Armstrong and Aldrin walk on the moon. In 1977 Voyager 1 and 2 set off and by 1990 send back stunning images from Jupiter, Saturn, Uranus, and Neptune.

As 2000 approaches, the Human Genome Project catalogs our genes, the Internet links scientists worldwide, and the Hubble telescope, in orbit since 1990, transmits intergalactic views.

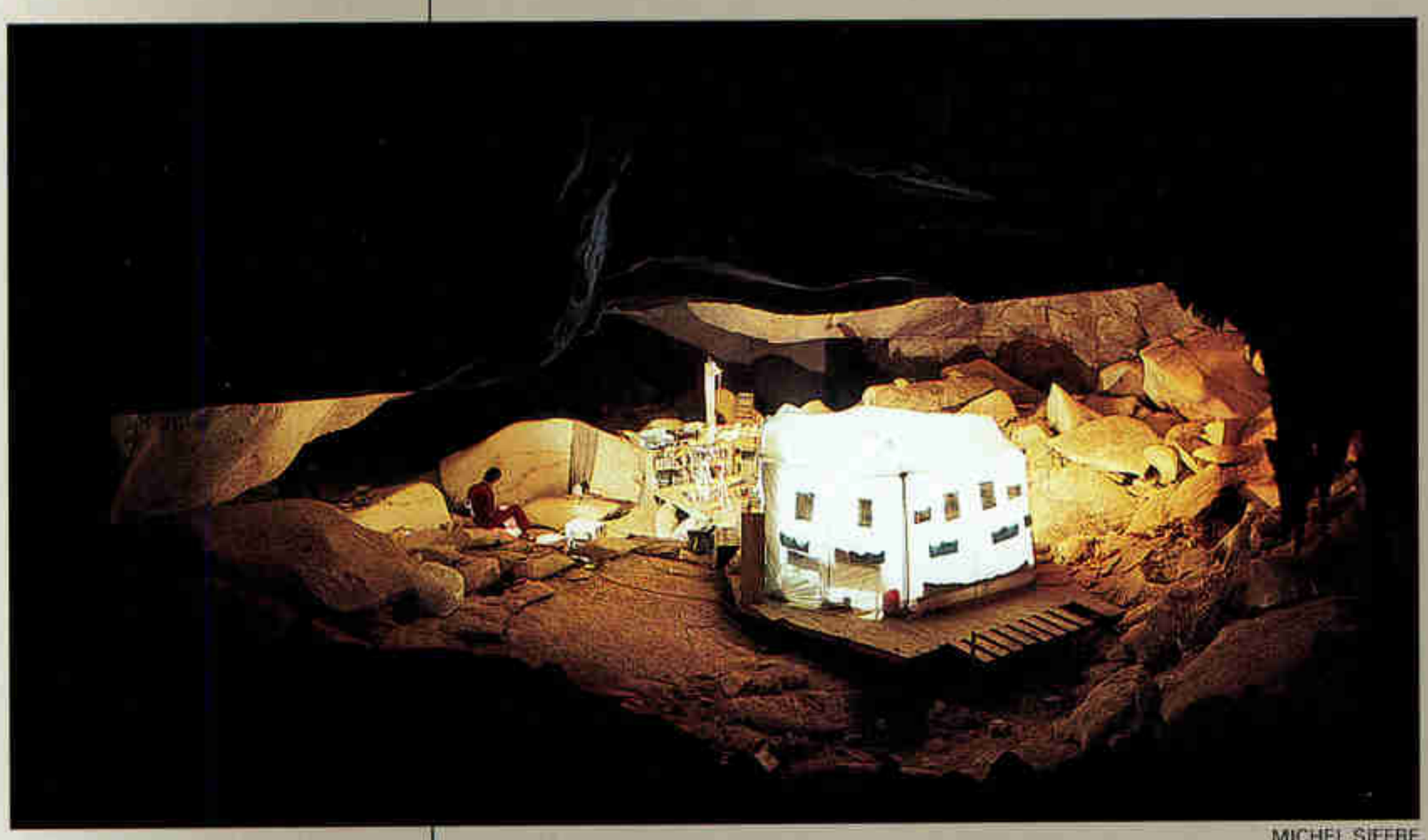


BRUCE DALE

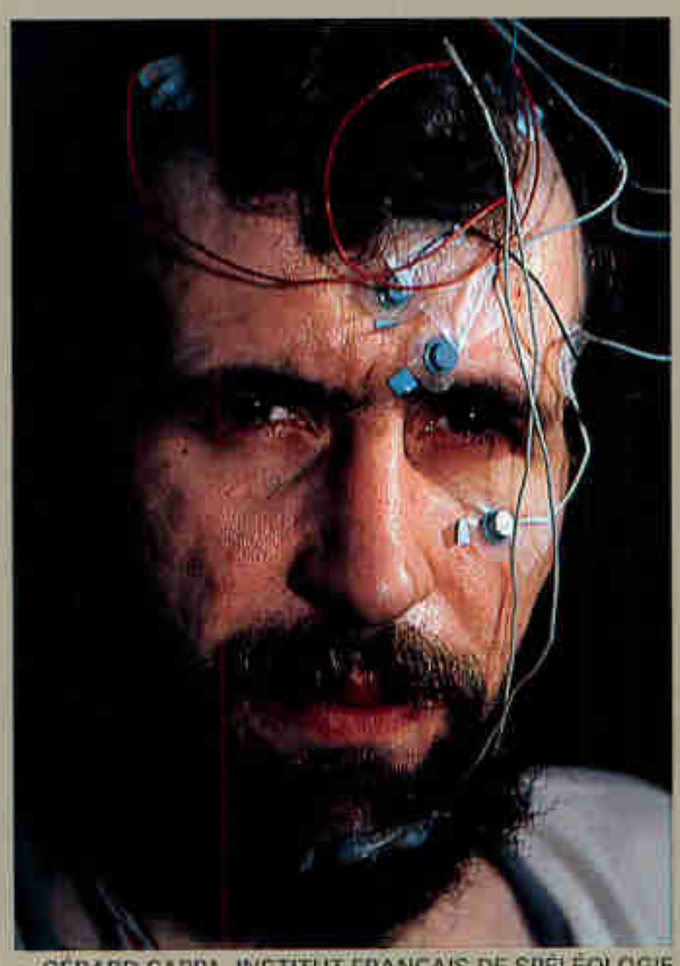
THE UNIVERSE WITHIN US

Another "what if" of space travel: How would astronauts react to prolonged isolation? In 1975 the magazine presented French geologist Michel Siffre's disturbing account of his six months alone in a Texas cave (below left). Wired to monitor his heart, brain, and muscle activity, Siffre (below) stayed 177 days, suffering "psychological wounds that I do not understand."

As astronomers watched distant galaxies moving away from their telescopes—legacy of the big bang—microbiologists used different but equally advanced optics to look the other way. Eagerly the GEOGRAPHIC joined these fantastic voyages seeking the building blocks of life. In a pioneering 1976 article,



MICHEL SIFFRE



GÉRARD CAPPA, INSTITUT FRANÇAIS DE SPÉLÉOLOGIE

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"The Awesome Worlds Within a Cell," University of Maryland chemist Cyril Ponnamperuma created organic compounds in his flasks (top), which contained gases that simulated Earth's primitive atmosphere. In his words, "it is with a feeling of awe and inadequacy that we approach . . . the sequence of events . . . which culminated in the appearance of life." The article also delved into the structure of the cell, unraveling its spiraled blueprint, the DNA molecule. A decade later "Our Immune System: The Wars Within" pursued the internal focus. On an unseen battlefield a macrophage (left), or body-defense cell, engulfs droplets of oil, a scene magnified 18,000 times by a scanning electron microscope. Medical boosts to human cells' wars against cancer and AIDS were described and illustrated in arresting detail.

In the new millennium, the GEOGRAPHIC will keep reaching for the stars, and for life's tiniest secrets.

CRASH DIET

Plastic soft drink bottles have been slimming down for years. Take today's popular two-liter bottles. They're 27% lighter than they were in 1990, but still as strong and shatter-resistant as ever. And, these leaner plastic bottles reduce the need for millions of pounds of packaging, helping to conserve precious natural resources. To learn more about the benefits of plastic packaging and our environment, contact the American Plastics Council at www.plastics.org or 1-800-2-HELP-90.

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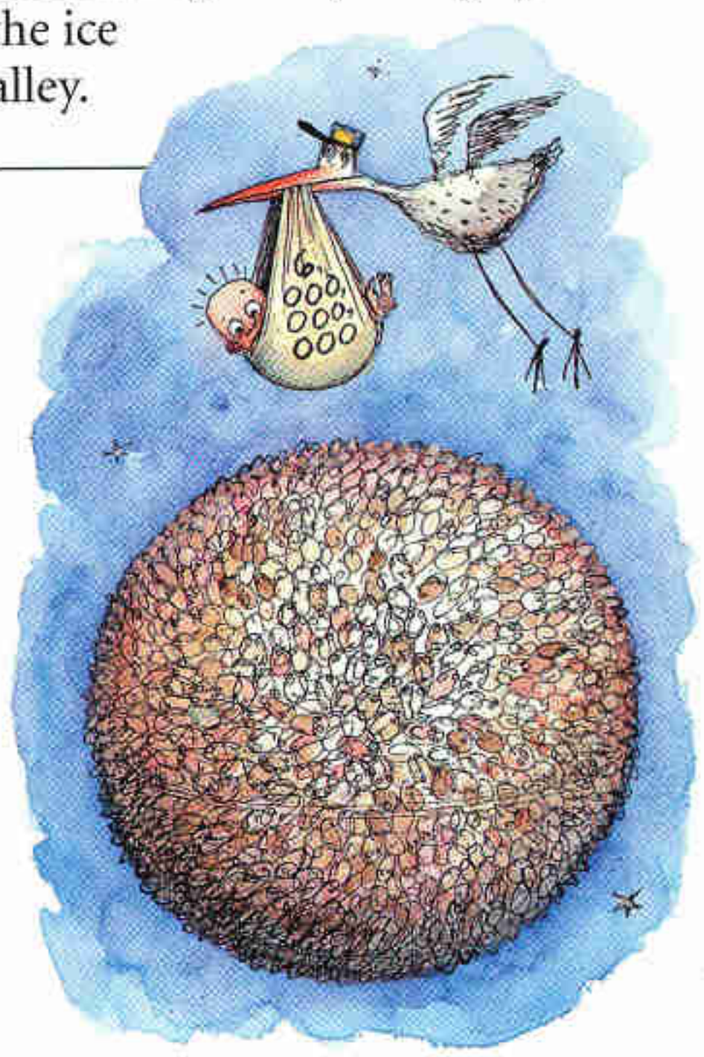
PATRICE HALLEY

Gathering Mussels Below the Ice Pack

Most ice fishermen simply bore a hole in the ice and drop a line through. But in northern Quebec, Inuit from the coastal village of Kangiqsujuaq squeeze through the hole and clamber down to the seafloor. Their quarry: succulent mussels ripe for the picking. For up to 90 minutes while the tide is out, the villagers make their way 10 to 12 feet beneath the ice to collect the mussels before the frigid water returns. "You're ankle deep in water, and melting ice pours through from above," says Patrice Halley, who photographed the practice. But mussel picking has a side benefit: It's far warmer below the ice than in the air above. "For us it's like going to Florida," one picker told Halley.



RICHARD THOMPSON

Global Population Reaches a Milestone

Take a look around on October 12, because it may seem a bit more crowded. On that day, or thereabouts, Earth's population will reach six billion. Although no one knows exactly when baby number six billion will arrive, the United Nations picked October 12 to mark the event, which is almost certain to occur before the end of 1999.

"Six billion is a benchmark," says Carl Haub, senior demographer at the Population Reference Bureau in Washington, D.C. The 20th century began with world population under two billion. "We've added the last billion people in only 12 years. That's phenomenal."

Most of the increase these days takes place in the developing world. "Birthrates have stabilized at low levels in Europe and North America," says Haub. "In the developing world the overall rate of increase is 1.7 percent a year, which would double its population in 40 years."

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PEACE OF MIND

A Complete Look at a Mystery Mammal

Triconodonts, small mammals with three-cusped teeth, made their debut on the evolutionary stage almost 200 million years ago. They had a long run, lasting a hundred million years before becoming extinct. But until now only their jaws, teeth, and skull fragments had been recovered for scientists to study.

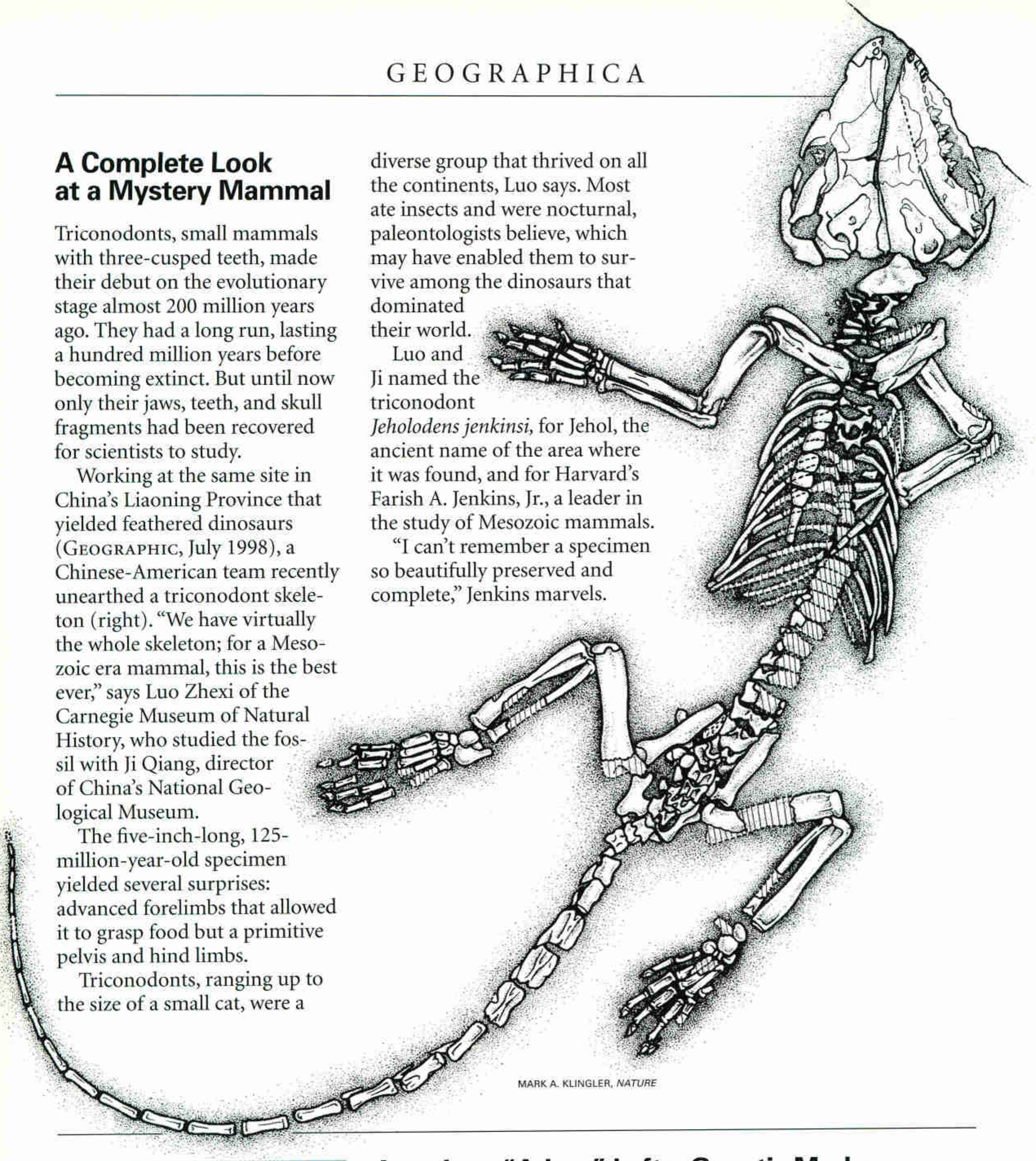
Working at the same site in China's Liaoning Province that yielded feathered dinosaurs (GEOGRAPHIC, July 1998), a Chinese-American team recently unearthed a triconodont skeleton (right). "We have virtually the whole skeleton; for a Mesozoic era mammal, this is the best ever," says Luo Zhexi of the Carnegie Museum of Natural History, who studied the fossil with Ji Qiang, director of China's National Geological Museum.

The five-inch-long, 125-million-year-old specimen yielded several surprises: advanced forelimbs that allowed it to grasp food but a primitive pelvis and hind limbs.

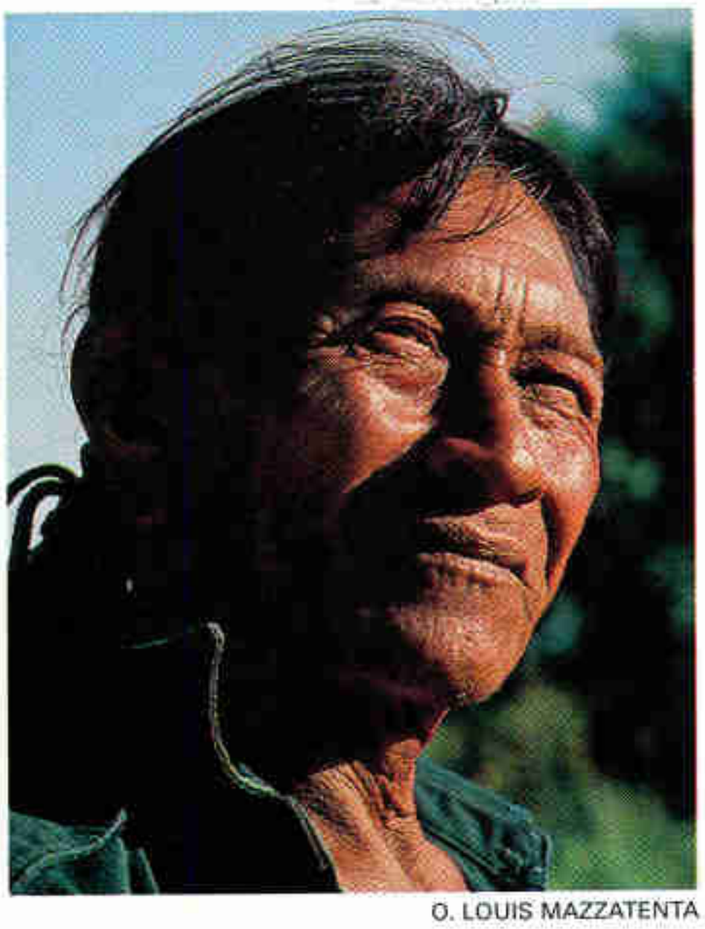
Triconodonts, ranging up to the size of a small cat, were a diverse group that thrived on all the continents, Luo says. Most ate insects and were nocturnal, paleontologists believe, which may have enabled them to survive among the dinosaurs that dominated their world.

Luo and Ji named the triconodont *Jeholodens jenkinsi,* for Jehol, the ancient name of the area where it was found, and for Harvard's Farish A. Jenkins, Jr., a leader in the study of Mesozoic mammals.

"I can't remember a specimen so beautifully preserved and complete," Jenkins marvels.



MARK A. KLINGLER, *NATURE*



O. LOUIS MAZZATENTA

American "Adam" Left a Genetic Marker

Sometime after humans came to the Western Hemisphere, 15,000 to 20,000 years ago, an extraordinarily rare genetic mutation occurred in one man who sired a son. The result was that the son's Y chromosome, usually an exact copy, varied ever so slightly from the father's.

Now DNA research shows that the son became a native American "Adam." Some 90 percent of South America's indigenous people and 50 percent of those in North America share that genetic marker, unknown in other male populations. "You can be from the Great Plains or from the Amazonian rain forest and have the marker," says Peter Underhill of Stanford University, whose population-defining work has been confirmed recently by other scientific teams. "They're from different ethnic groups, have different cultures, and speak different languages, but they share that common male ancestor."

TEXT BY BORIS WEINTRAUB

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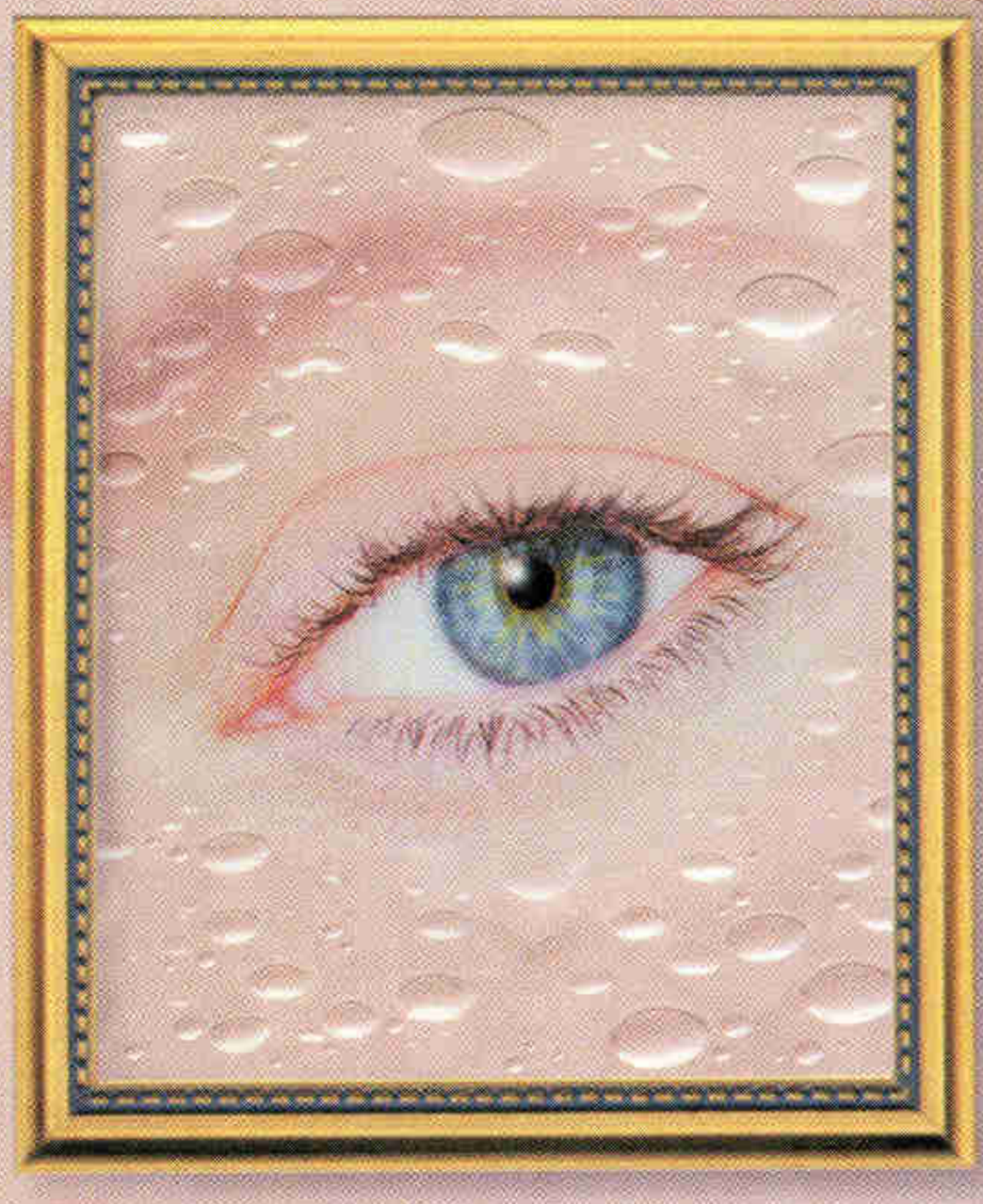

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Forum

The June cover story on Cuba generated passionate responses from our readers, especially from those with family ties to that country. From the other side of the world, a Peace Corps volunteer in Ghana wrote that the magazine has "reached right into the heart of a small African village and made a difference—even for those who are not able to read. . . . giving me the means to widen the horizons of people who deserve it."

Cuba: Evolution in the Revolution

Your article provided two points of view, as opposed to the usual monotone voice that speaks about how Fidel Castro resembles the devil. Too many times, through school textbooks and strongly opinioned teachers, students are exposed only to the vile, overbearing side of Fidel and his militant government. My mother, however, grew up in the late 1950s and '60s in Guatemala, where Castro was seen by many as the deliverer of the Cuban people from the dominating hand of U.S. interests. Thank you for bringing a part of history alive, as you so often do. You have put faces and names and actual lives behind the numbers and statistics in my textbook.

A. DAVID LINDES
Watsonville, California

For 37 years and four months in this country as a Cuban exile, I have never read such an unbiased description of what is happening in Cuba under the tyranny. I am grateful to John J. Putman and David Alan Harvey and to NATIONAL GEOGRAPHIC for printing this so necessary information about life in the Cuba of today.

LUIS F. ERA
Chicago, Illinois

Where are the pictures of Havana's political prisoners rotting away in rat-infested dungeons? This article appears to be nothing more than a propaganda piece for Fidel Castro.

DOMINICK M. FURLANO
East Stroudsburg, Pennsylvania

A Dinosaur Named Sue

Because of the fantastic price paid for Sue, ranchers have started refusing permission to scientists to collect fossils on their properties, preferring to mine the fossils themselves and offer them for sale. This not only damages fossils because of improper removal but also severely limits the science that may be performed on them. As the most complete *Tyrannosaurus rex* ever found, Sue is a great gain for science, but the precedents set by her removal, custody battles, and sale may well do more harm than good.

TIMOTHY FARNHAM
Department of Geological Sciences
University of Colorado at Boulder
Boulder, Colorado

On what grounds do the scientists working on Sue conclude that large olfactory spaces are evidence of large olfactory bulbs (page 51)? Aren't there other large spaces in other organisms' skeletons that are not filled with sense organs? Even if the olfactory sense organ is large, that does not necessarily mean that smell was the critical sense in *T. rex.*

JAMES TIMOTHY STRUCK
Chicago, Illinois

Paleontologist Chris Brochu of Chicago's Field Museum of Natural History, who is doing research on Sue, agrees that it's impossible to know whether a cavity in a fossil skull held a soft-tissue structure, but he based his conclusion on comparative anatomy: The spaces correspond precisely with the olfactory bulbs in all living reptiles. There is evidence in living mammals and birds that olfactory bulb size corresponds to olfactory acuity.

John Glenn: Man With a Mission

I was born on April 12, 1961, the very day that man first went into space, and I have followed the exploration of space with keen interest all my life. The tremendous dedication and bravery shown by Glenn on his repeat flight was astonishing—even more remarkable for a man well past retirement age. I share Senator Thurmond's view, "I want to go too." I can only hope that the advances made by science will enable me to achieve this ambition by the time I am John Glenn's age, in 2038.

NICK BLOOMFIELD
Milton Keynes, England

I am a flight attendant. When I learned of the launch date last October, I checked my flight schedule to verify my hunch. Sure enough, my flight from Miami to Richmond, Virginia, was leaving at the perfect time. As we approached Cape Canaveral, I noticed two small aircraft close to the launch area and later learned they were the cause for the delayed liftoff. Just as I was convinced that we would be too far past the site to see anything, a passenger yelled, "There it is!" Everyone on board crowded around the right side windows to see the space shuttle and the huge pillar of white exhaust coming up and then continuing above us. I watched until I could no longer see the glow of the rockets—or was it when a passenger said, "Excuse me, can I get a drink here?"

BILL MARBLE
Temecula, California

Tam Dao—Sanctuary Under Siege

Each summer between 1933 and 1943 my mother and I spent at least a month at Tam Dao to avoid the hot Hanoi weather. The other boys and I would clear a path in the jungle with a *coupe-coupe,* a sort

of long knife, and play Tarzan. We constructed shelters up in the trees, collected beetles and butterflies, and admired forest life: birds, bats, flying squirrels, lizards, and snakes (killing here and there a cobra). Of course, our mothers had absolutely no idea of our exploits, knowing only the leeches collected during quiet adult walks along the well-laid paths of the south and north peaks. Thank you for having allowed me to dream of such wonderful moments of my youth.

JACQUES E. DIETRICH
Nice, France

The photograph of the snake that had been skinned and gutted alive, writhing in unspeakable agony, prompts me to write that to eat is one thing, to torture is another.

CYNTHIA RUDDY
Farmingdale, New Jersey

Tam Dao provided protection for us too on bombing raids into North Vietnam during the Vietnam War, only we called it Thud Ridge, for the F-105 Thunderchief. We thought the mountains would be a good place to bail out if the need arose, but we could only fantasize how we would get "home." At least the sanctuary would have provided cover and food if we were shot down.

ROBERT W. SPIELMAN
Reno, Nevada

Ancient Art of the Sahara

The power and beauty of these figures reveals what Miró noticed: "Painting has been in a state of decadence since the age of the caves." The Trust for African Rock Art is doing invaluable work in preserving what is much more than the decoration of an ancient era—it is the record of means by which the human spirit can advance.

DANIEL C. BOYER
Houghton, Michigan

I was surprised at Coulson's reference to "The Crying Cows" (page 110) when he commented, "I was stunned by its almost Picassoan sophistication." Both Picasso and Matisse, among others, were influenced by African art, including images from cave paintings and engravings. It is time that we acknowledge the contributions Africa has made to world history, which includes the arts.

L. TERRY BRUSSTAR
Fayetteville, Arkansas

The art in the Sahara desert is one of the most evocative things I have ever seen. The purity and power contained within those graceful lines resonates through the ages to strike a chord of wonder and appreciation in my soul.

TERESA A. DELAFOSSE
Jamestown, North Carolina

Deep Soul of the New River

On page 124 it states that the New River "is a testament to raw power, contrariness, and endurance." This aptly describes Mary Ingles, who in 1755 was kidnapped by a Shawnee raiding party from her Virginia farmhouse along the New River. She escaped near present-day Cincinnati, Ohio, and backtracked 800 miles, nearly naked and on foot, to her home. Your fascinating article documents that the very character of Mary Ingles has permeated the New River and its people of today. Or did she also pick it up from the river?

RUSSELL J. FINK
New York, New York

Your article reminded me of my own youthful white-knuckled, pale-faced runs up, down, and around the West Virginia mountains en route to my grandfather's farm. My brother and sister held me down on the floor of our Hudson automobile in hopes I wouldn't stir and start a motion-sickness chain reaction. I dare some of those white-water rafters to get behind an 18-wheeler going ten miles an hour through every nook and cranny of a West Virginia mountainside and then come talk to me about adventure.

CAROLYN ANN WILLIAMS
Detroit, Michigan

Flashback

You noted that in the cigar factories "the leaf rollers' daily tedium was eased by a *lector* on an elevated platform, who read aloud from newspapers, novels, union tracts, even letters." In one such factory the lector read from Alexandre Dumas's works repeatedly, at the request of the workers. So much did they love his work that they wrote and asked permission to name a cigar in his honor. Thus was born the Montecristo, forever memorializing that famous count.

SUSAN AND NEIL KAYE
Wilmington, Delaware

It was with delight that I turned to the photograph of a lector in a Cuban cigar factory. I recently learned that my great-grandfather was a reader in a cigar factory in Manchester, Maryland, in the 1880s, reading everything from Shakespeare to the daily news. It must have been quite different from the pop radio stations that factory workers listen to today.

JENNIFER SAUER
Oakland, California

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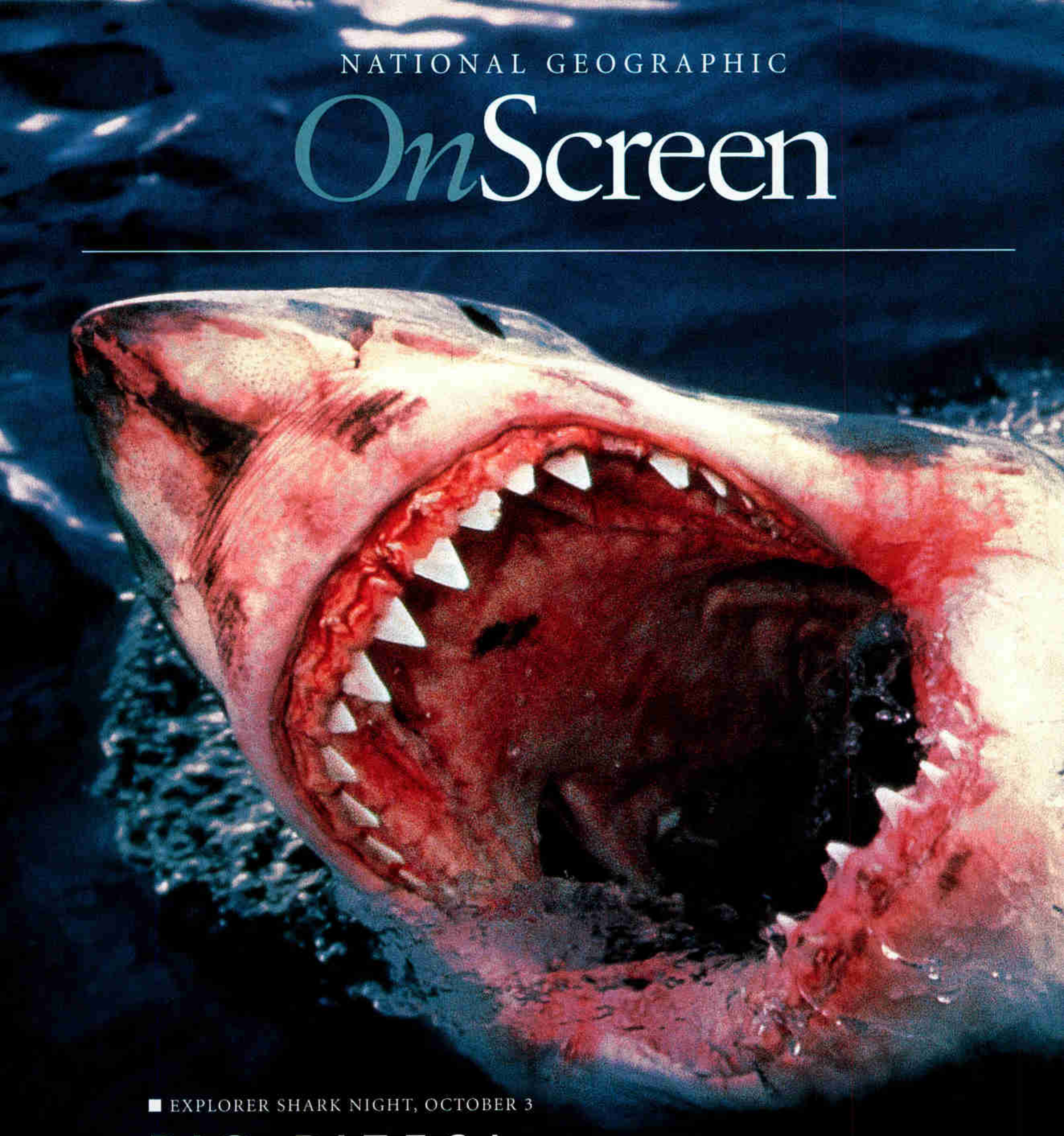

■ EXPLORER SHARK NIGHT, OCTOBER 3

BIG BITES!

Sharks yield their secrets grudgingly. But in October EXPLORER will take a bite out of the awesome predators' riddles. Off California biologists feed great whites transmitters that signal location and stomach temperature, revealing hunting strategy. In the Florida Keys the mysteries of nurse sharks' violent courtship are exposed. The results defy expectations. Great whites seem to have a discerning sense of taste, and although mating nurse sharks play rough, their lineage is at stake. "We've seen things never before studied in the ocean," says John Francis, producer of *Tracking the Great White.* "For the first time, we've been able to watch the dance between predator and prey."

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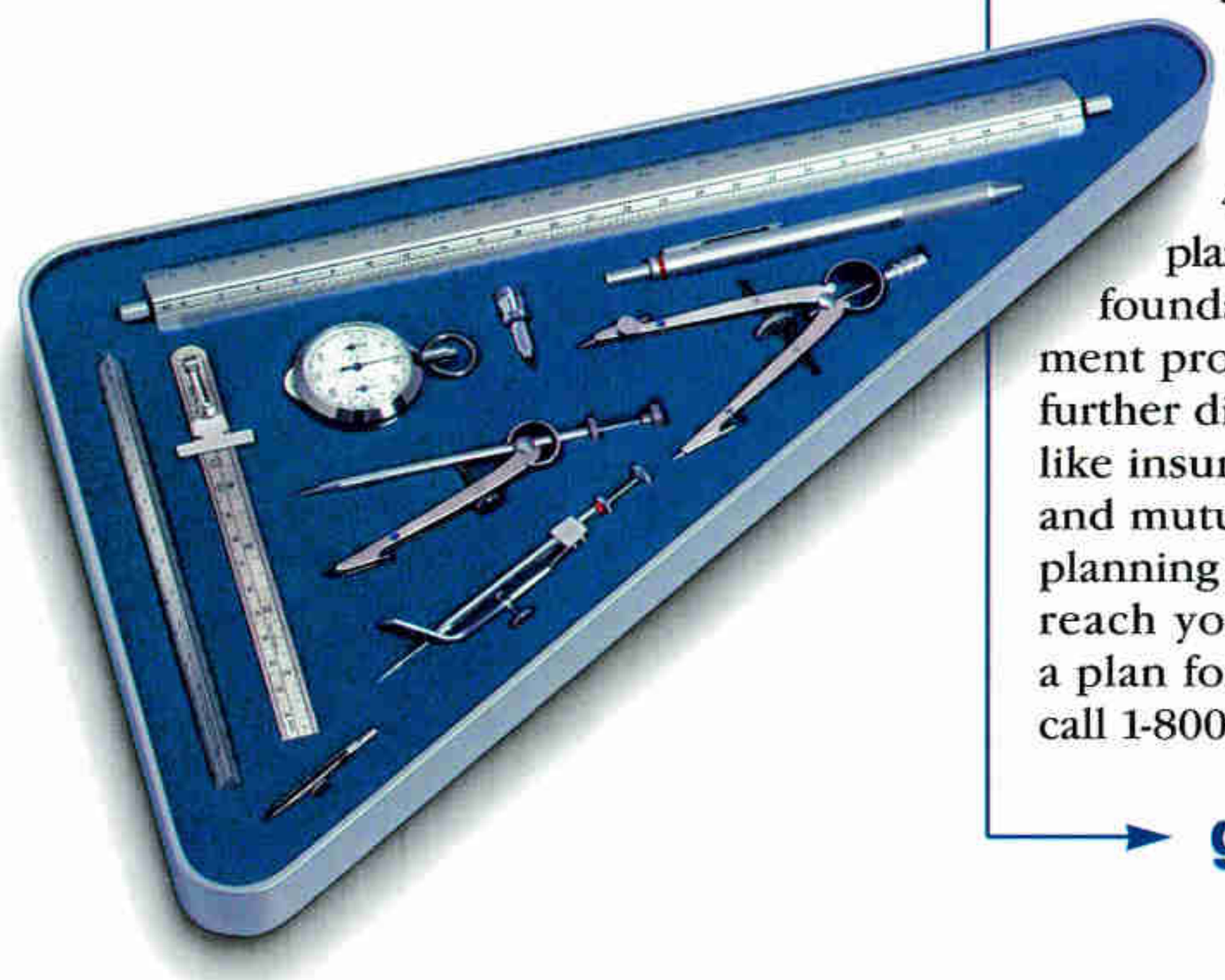

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NATIONAL GEOGRAPHIC

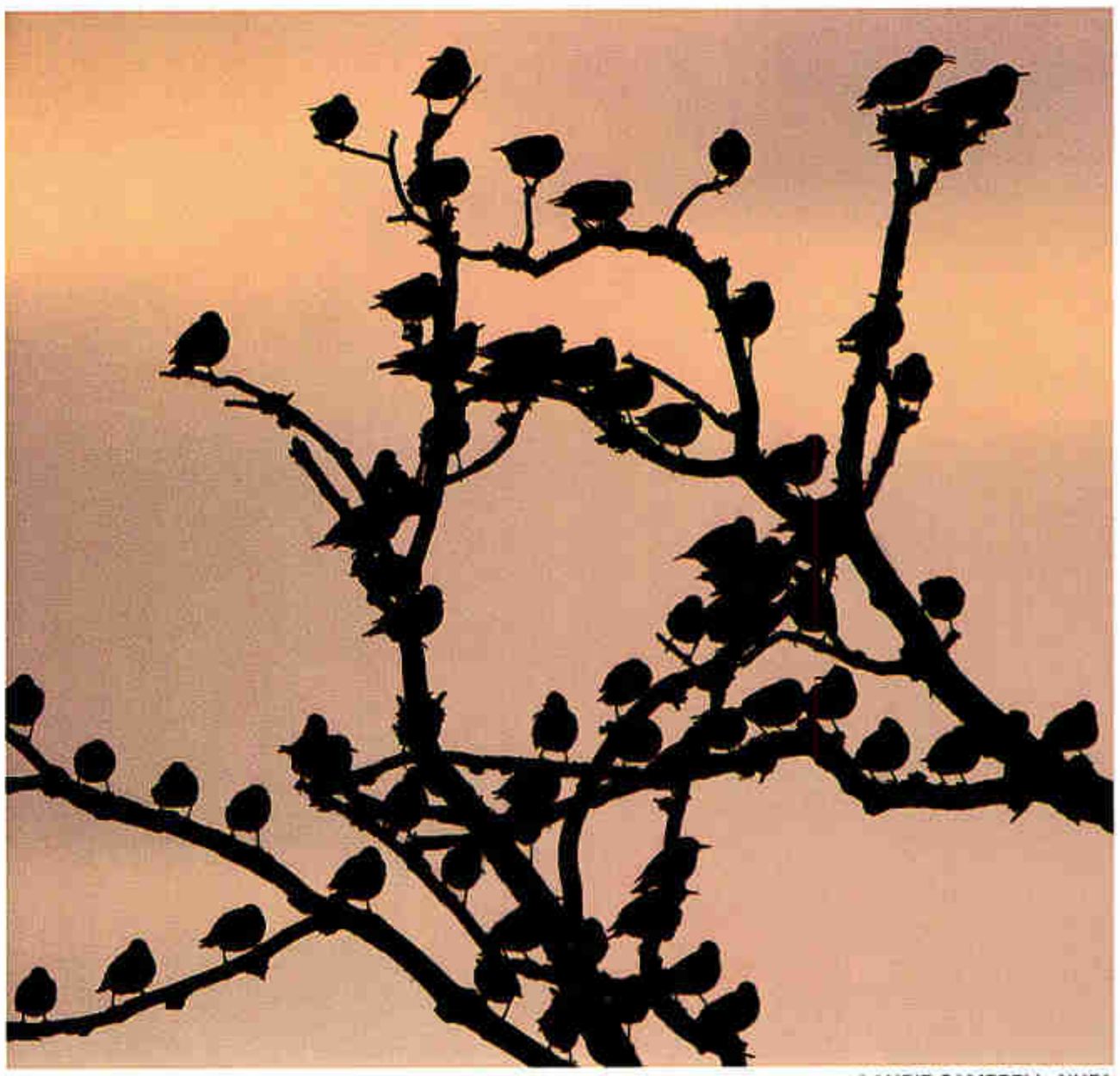
Earth Almanac

Silence of the Starlings

Perhaps 600 million starlings darken the skies over Europe, Asia, Africa, and North America. Yet in Britain, European starlings are crashing, and an unofficial red alert has been declared by the British Trust for Ornithology. Since 1972 the starling population has plummeted from about twenty million to ten million, says Richard Gregory of the Royal Society for the Protection of Birds. "There is no sign of recovery," he adds.

He and his colleagues suspect that pesticides and the loss of pastureland have eliminated many insects on which starlings feed.

"We may need some of the American starlings to be returned," Gregory jokes. Sixty birds released in New York's Central Park in 1890 have now exploded to some 200 million in North America.

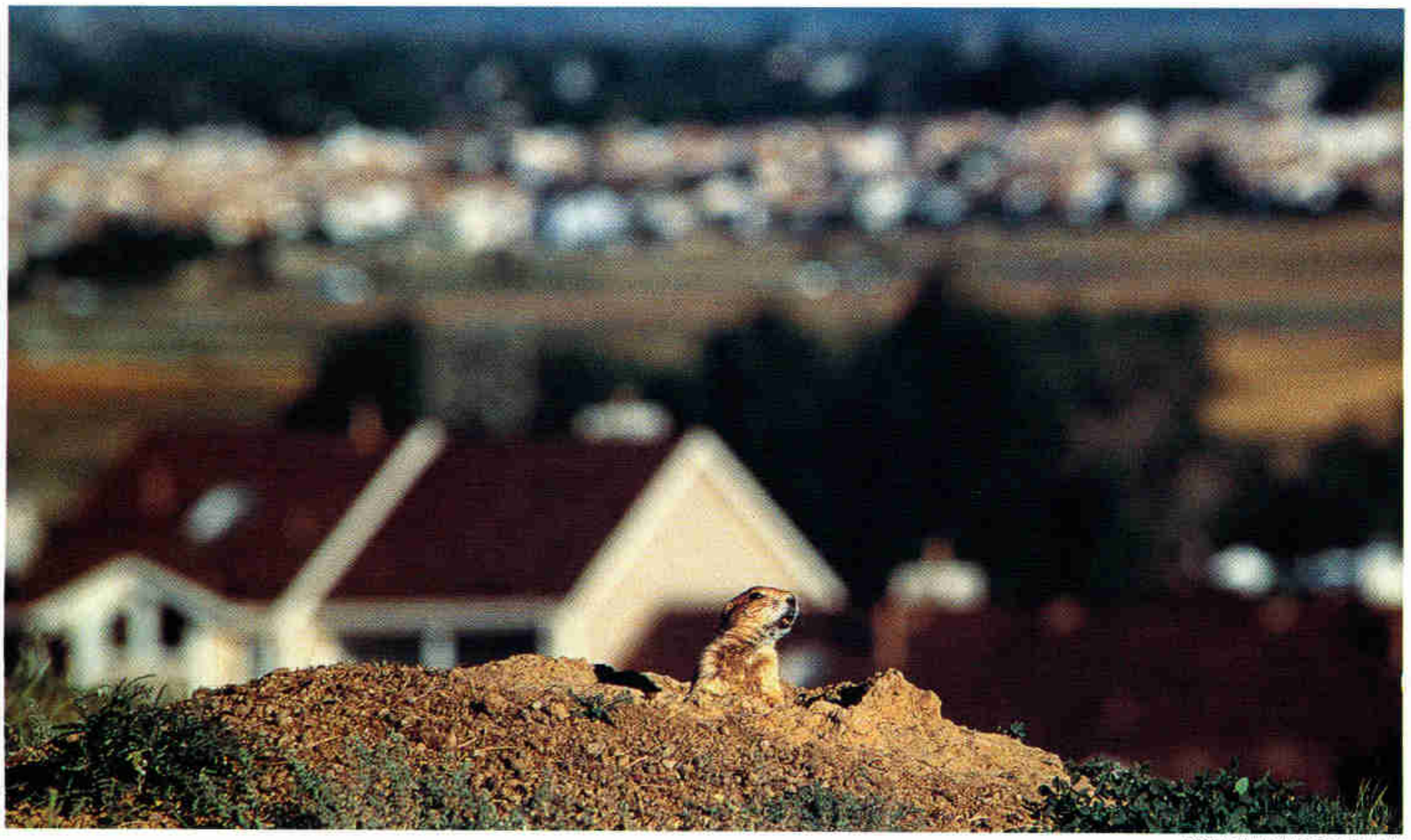


LAURIE CAMPBELL, NHPA

Brown Bears, Polar Bears: A Surprising Link

You'd never know just by looking at it, but this brown bear on Admiralty Island in southeastern Alaska is more closely related to polar bears than to other brown bears. Gerald Shields and a University of Alaska team examined DNA from some 450 bears in Eurasia and North America. They concluded that polar bears and the browns on Admiralty and nearby islands emerged from a common ancestor, perhaps 40,000 years ago. Moreover, among brown bears, the isolated island bears are the only surviving descendants of that ancient ancestor; all other New World brown bears spring from more recent stock.

DANIEL J. COX, NATURAL EXPOSURES



BOTH BY RAYMOND GEHMAN

Black-tailed Prairie Dogs: Persecution to Protection?

Burgeoning Denver suburbs loom behind a black-tailed prairie dog. The long-persecuted species (GEOGRAPHIC, April 1998) may be at a crossroads. This past March the U.S. Fish and Wildlife Service began a nine-month review to decide if blacktails are an endangered species. Officials in 11 states seek to prevent a federal listing with their own protective measures, which might include shooting limits. In three months, perhaps as many as 320,000 prairie dogs were shot in one 9,000-acre South Dakota colony. Though they may number 12 million, blacktails have been eliminated from 98 percent of their range by habitat loss and poisoning. Last May the U.S. Forest Service stopped poisoning prairie dogs, but another major danger, plague, is killing the animals.

PSEUDOPALLENE SP., GARY BELL, PLANET EARTH PICTURES

Nice Legs, but Not Just for Show

Crawling among corals, anemones, and sponges to suck their juices, marine creatures called sea spiders range all oceans. This one was photographed off Australia. But sea spiders have a problem. Their bodies are so tiny—usually just a few millimeters in diameter—that there isn't room for all their internal organs. So their legs serve as auxiliary storage, housing part of their digestive and reproductive systems. Males carry females' eggs on a special pair of legs, called ovigers, until they hatch.

TEXT BY JOHN L. ELIOT

HELMUT LANG

double layered shearling coat and silk t-shirt

surplus coat with universal collar, detachable shearling lining, and silk t-shirt

photographed © by JuergenTeller/Backstage N.Y. 3/99

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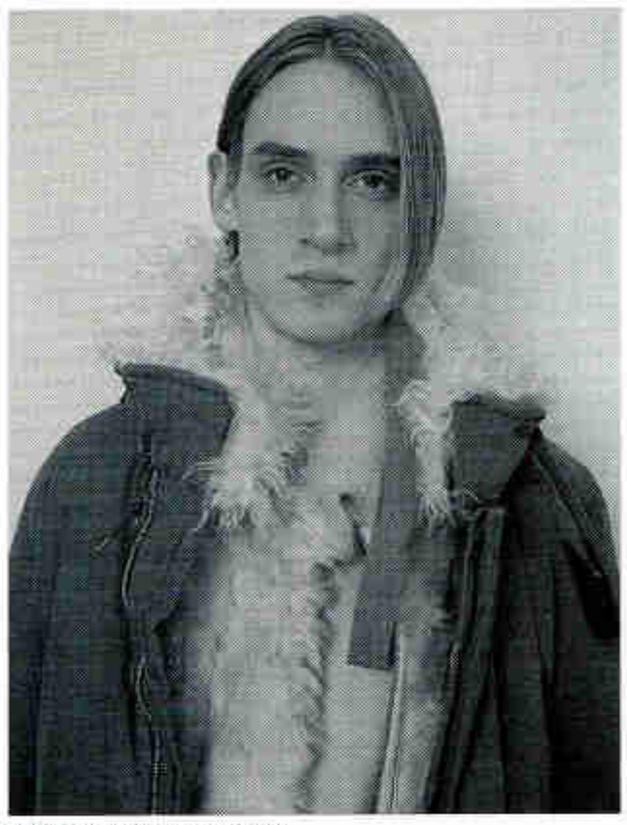

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NATIONAL GEOGRAPHIC MAGAZINE

Smooth-skinned Leaf-tailed Gecko *(Uroplatus malama)* **Size:** 120 mm **Weight:** 10 g **Habitat:** Rainforest in southern Madagascar **Surviving number:** Unknown

Photographed by Ronald A. Nussbaum

WILDLIFE AS CANON SEES IT

A master of disguise, the smooth-skinned leaf-tailed gecko hunts for insects in tree branches by night and sleeps undetected by day pressed against a tree trunk. If disturbed, the gecko screams—an attempt to startle the predator long enough to make its escape. Only recently discovered, this leaf-tailed gecko was named for the Malagasy word "malama," meaning smooth. Its smooth skin sets it apart from related gecko species, whose skin is always ornamented with spines or bristles. The future of the smooth-skinned leaf-tailed gecko is uncertain as its remaining rainforest habitat disappears. As a global corporation committed to social and environmental concerns, we join in worldwide efforts to promote greater awareness of endangered species for the benefit of future generations.

NATIONAL GEOGRAPHIC

JOE McNALLY

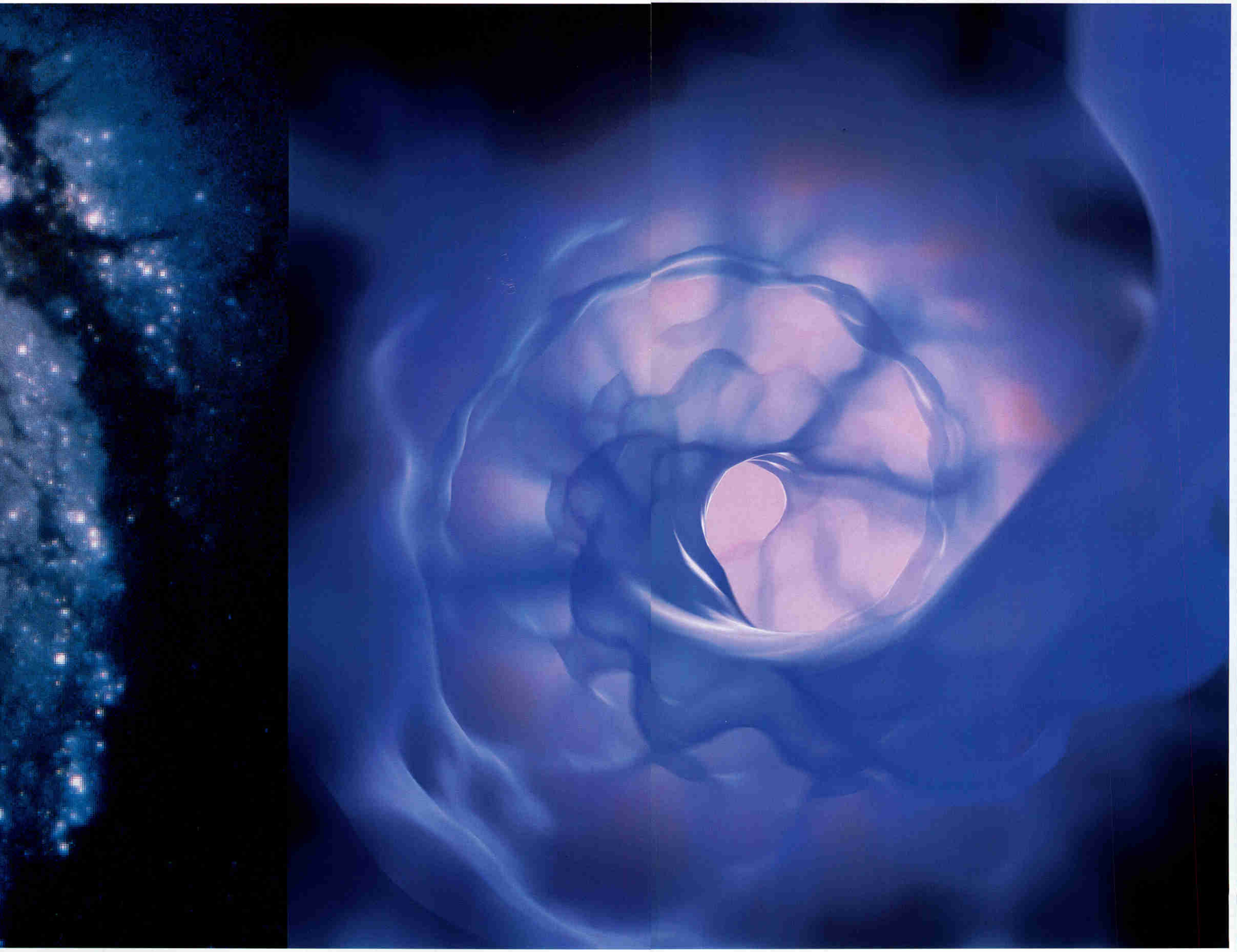
From the Editor

THE LAST TIME a photographer for NATIONAL GEOGRAPHIC flew over the site of the Very Large Telescope (VLT) array on Cerro Paranal, Chile (below), the only sign of human presence was a sheared-off mountaintop. Today four domes rise from the man-made plateau (above), and two of the four huge telescopes are probing the heavens. This transformation illustrates the dramatic advances in astronomy between our 1994 article "New Eyes on the Universe" and this month's report. For example, astronomers have observed galaxies that formed early in the history of the universe and have detected planets orbiting other stars. While for now we seem to be alone in the universe, the search for life beyond Earth continues.

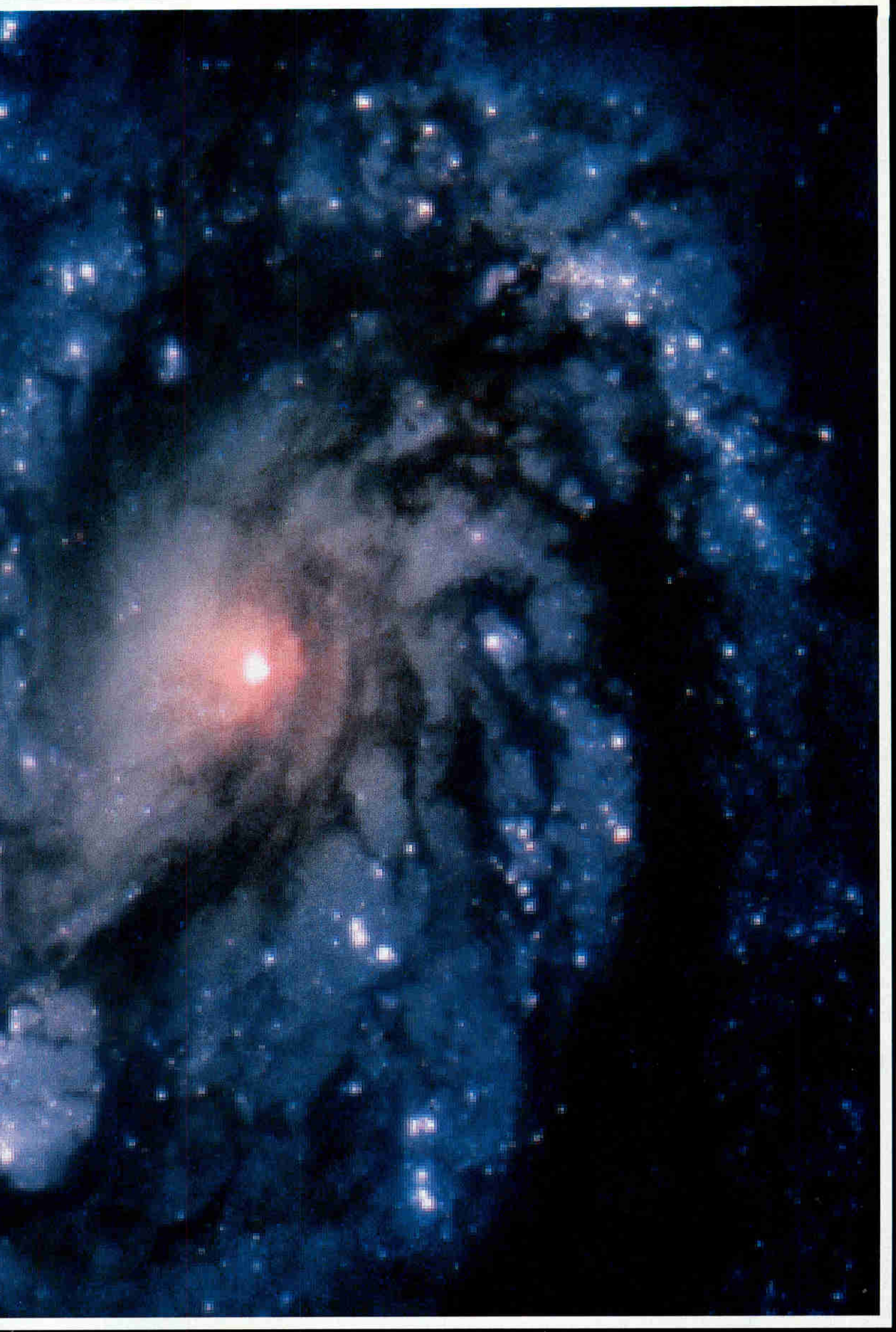
ROGER H. RESSMEYER

With its surprising twists, science is a lot like life. I started out studying physics, and Bill Douthitt, who selected the images for our universe story, wanted to be an astronomer. Now as journalists we're both immersed in the subjects we first loved. And, like scientists, the more we learn, the more we want to know.

Bill Allen



SPACE TELESCOPE SCIENCE INSTITUTE AND NASA (LEFT); KEN EWARD, BIOGRAFX



Asking Infinite Questions

SCIENCE

A distant galaxy and a model of DNA spiral into view with suggestive symmetry. The universe and life both seem to be self-organizing. But how do they work? Edwin Hubble observed that galaxies are rushing apart in what must be an expanding universe. James Watson and Francis Crick decoded the molecule essential to life. Such breakthroughs follow when answers to novel questions withstand rigorous scientific testing.

By JOEL L. SWERDLOW
ASSISTANT EDITOR

"What good is discovery if you can't

PLANTS CAN COMMUNICATE with each other. ■ Ilya Raskin, a botanist at Rutgers University, shows me how he and his colleagues demonstrated this in an experiment. ■ Dozens of tobacco plants, chosen because of their strong chemical response to a particular virus, were placed in two airtight chambers. Tubes carried air between the chambers. The scientists injected the plants in one chamber with the virus. Within two days those infected emitted a volatile chemical into the air, stimulating the plants in the second chamber to produce chemicals in their leaves that protected them against the virus. ■ This experiment followed the model that guides most scientific research today: Develop a hypothesis, run tests, and produce data that other researchers can confirm or challenge by conducting similar experiments. ■ Until recently botanists did not understand chemicals like those produced by the tobacco plants. But now it's known that plants generate an array of chemicals that protect them against disease and also help them reproduce. Knowledge about such chemicals could lead to the development of hardier plants and to changes in our basic understanding of how they function. ■ "But there's still a huge amount going on in plants that we don't understand," Raskin tells me. ■ Such vast gaps in our knowledge exist in virtually all branches of science. As James Shreeve points out in "Secrets of the Gene," scientists are making extraordinary advances; nonetheless, the purpose, if any, of most information coded in human DNA is not known. Likewise, Kathy Sawyer shows in "New Light on the Universe" that most of the mass that fills the universe has yet to be located. ■ To decipher scientific enigmas, it helps to be willing to challenge conventional wisdom. Such wisdom once assumed that the universe was static and unchanging. Now an expanding universe and the big bang theory are cornerstones of cosmology, the part of astronomy that studies the origins of the universe and its time–space relationships. ■ Advances in genetics and astronomy are driven by the number-crunching capabilities of faster computers and by improved imaging techniques that make microscopes and telescopes more powerful. Such tools enable scientists to see things they had never seen before or even considered possible. Genetic researchers can examine objects that are only a millionth of an inch in diameter, while astronomers can see galaxies

celebrate it with firecrackers?"

—JOHN A. WHEELER, THEORETICAL PHYSICIST

perhaps 11 billion light-years away. ■ It's easy to forget how revolutionary modern science really is. ■ Just a few hundred years ago, in the 16th and 17th centuries, most Europeans thought that the sun revolved around the Earth and that four elements—air, fire, water, and earth—created and defined all life. Scholars mostly parroted what they had learned from classical writers like Aristotle, who believed, among other things, that the Earth was enclosed by celestial spheres where nothing ever changed and everything was always perfect. Then pioneers such as Galileo Galilei and Isaac Newton demonstrated that the natural world can be best understood by experimentation and analysis. ■ Why didn't the scientific revolution (a phrase that didn't come into popular usage until the mid-20th century) take place much earlier? Ancient Greek mathematicians and astronomers had calculated the circumference of the Earth, charted the stars, and figured the distance to the moon. By A.D. 1100 Chinese scholars had developed a seismograph, a magnetic compass, and the concept of infinite empty space. Why didn't the scientific revolution occur in either of those places? Among the best guesses so far: Only in 16th-century Europe did scientists begin to embrace quantification, the use of mathematics to measure the results of experiments. ■ One of the most significant effects of the scientific revolution has been population growth. Until modern science brought sewer systems and immunization in the 19th century, about half of all children died before age five. By the end of the 19th century childhood death rates had fallen, and human population began to surge. With advances in medicine, population continues growing —and further challenging our ability to live in harmony with nature. ■ Will scientific progress continue? Or will science reach some limit like the Pillars of Hercules, the classical and medieval symbol for what lies at the edge of the known? On these gates, according to legend, was written: "*Ne plus ultra*—No further." The Pillars of Hercules for modern science may become moral and spiritual. Scientists—and society—will have to decide how much to change the genetic structures of plants and animals, and whether to tinker with the very genes that make us human. ■ In the meantime the achievements and challenges of modern science propel us further into the unknown. □

The millennium series concludes in December with a look at National Geographic's pioneering use of photographic techniques and a survey that reveals details of the geography of our personal lives.

For more on science and technology millennium coverage, go to nationalgeographic.com/2000/science.

UN

By KATHY SAWYER

Photographs by JOE McNALLY

Eclipsing the moon, an engineer focuses a projected image on a screen at Hawaii's W. M. Keck Observatory, a major portal for a new age of cosmic exploration.

Unveiling the UNIVERSE

NIGHT BEGINS 13,800 feet up on Mauna Kea, and the dome shutters open atop the ten-meter-wide Keck I and II telescopes. They are among Earth's most advanced: Each has a mirror made up of 36 hexagonal segments that can be individually adjusted by computer.

By late 2000 they will work in tandem, creating a telescope with as much resolving power as a single mirror 85 meters in diameter. At full power the Kecks will study very distant or faint objects such as planets circling other stars.

GARY PUNIWAI SITS at the controls of the world's most powerful telescope on the summit of the highest peak in the Pacific, swaddled against the cold. In the eastern sky Orion the Hunter wheels above the horizon, taking aim at the infinite. Puniwai himself hunted wild pigs and sheep on this mountain as a boy, with his brother and two sisters. Now, as operator of the ten-meter-diameter Keck I telescope, he pursues more exotic quarry across the cosmic outback. Night after night Puniwai mans an array of five computer monitors, pointing and clicking to swivel the business end of the 700-ton domed structure toward black holes, exploding stars, gamma-ray bursts, the hiding places of alien worlds, and other phenomena targeted by an international parade of visiting astronomers. But tonight the massive dome won't budge.

HE'S SEEN ONLY on closed-circuit TV, but Gary Puniwai (opposite) has real star power. An observing assistant in the Keck Observatory control rooms on Mauna Kea, he points the telescopes in response to requests from astronomers at the telescopes' home base 48 miles away. Today more and more astronomers are taking advantage of remote technologies to make observations.

In recent days a life-threatening combination of fog, snowstorms, gale-force winds, and black ice on the treacherous, cliff-edged approach roads has periodically forced everybody to abandon the summit and retreat to a base camp farther down. This has meant shutting down all dozen of the telescope facilities that bristle here on the 13,800-foot heights of the dormant volcano Mauna Kea, an otherworldly landscape on the Big Island of Hawaii. Two days earlier an astronomer who flew from England for his one night of observing, booked more than six months in advance, was forced to return home without so much as a microsecond of telescope time.

This evening's disaster is the result of melted snow that seeped through a faulty seal and, at a temperature registering about 20°F, froze in the dome's track. Just before the sun sank with a blood-red splash into the sea of cloud lapping at the volcano's lower slopes, the dome's drive gears locked.

The shaken and exhausted day crew struggled for hours to free the dome, hampered by frigid gusts and lack of oxygen—about half that at sea level—which can cause headaches or vomiting and impair the judgment and memory of the most seasoned worker. They tried pouring antifreeze onto the track. No luck. They tried using a four-wheel-drive van to pull on a cable tied to the dome. The cable snapped. They mobilized a jack with seven tons of force to free the dome but gave up when a support strut began to bend. The icebound dome stared fixedly eastward.

Puniwai, whose authority approximates that of a ship's captain, could have shut down operations. But he prides himself on being conscientious. Besides, this is not some sleepy backwater of science but the booming frontier of trans-cosmic exploration. The night's assigned observers, Matthew A. Malkan of UCLA and Harry I. Teplitz of NASA's Goddard Space Flight Center near Washington, D.C., are not about to surrender easily their few hours of Keck time, valued at about a dollar a second. So they're all running through their options. "We're playing with sky now," Malkan says tensely. "This is very unplanned. . . . It's wild."

To the ancient Egyptians the heavens were almost close enough to touch—a benign canopy of light and dark held up by mountain peaks. But modern science has exploded that ancient, peaceful mirage, replacing it with a cosmos of violence, change, and processes that sometimes defy human understanding. Guided by leaps of imagination and armed with potent new technologies souped up in part as a result of Cold War military advances, scientists have expanded the reach of experimental testing and

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KATHY SAWYER is a staff writer at the *Washington Post*. This is her first contribution to the GEOGRAPHIC. JOE MCNALLY, a frequent contributor, chronicled John Glenn's return to space for the June 1999 issue.

claimed the universe itself as a titanic laboratory. Intruding on mysteries previously confined to the realms of philosophy, metaphysics, and religious faith, these audacious seekers seem on the verge of answering fundamental questions about the origins, scale, and fate of the observable universe, the nature of its contents, the prevalence of other Earth-like worlds—and the potential for kindred consciousness on some of them.

But the universe does not relinquish its secrets easily. For their allotted time with Keck I, Malkan and Teplitz had targeted a list of newborn galaxies eight to ten billion light-years away in the young universe. They intended to study them at infrared wavelengths by using an imager that, attached to the telescope, is capable of detecting the equivalent of a single candle flame on the moon. But the ice seizure forced them to abandon their target list. In a display of resilience under pressure and easy command of an array of high-tech tools—some of which did not exist as recently as two years ago—the two observers turned to the Internet, searched astronomy catalogs, and found all the objects that would pass through the dome's frozen field of view as the Earth rotated.

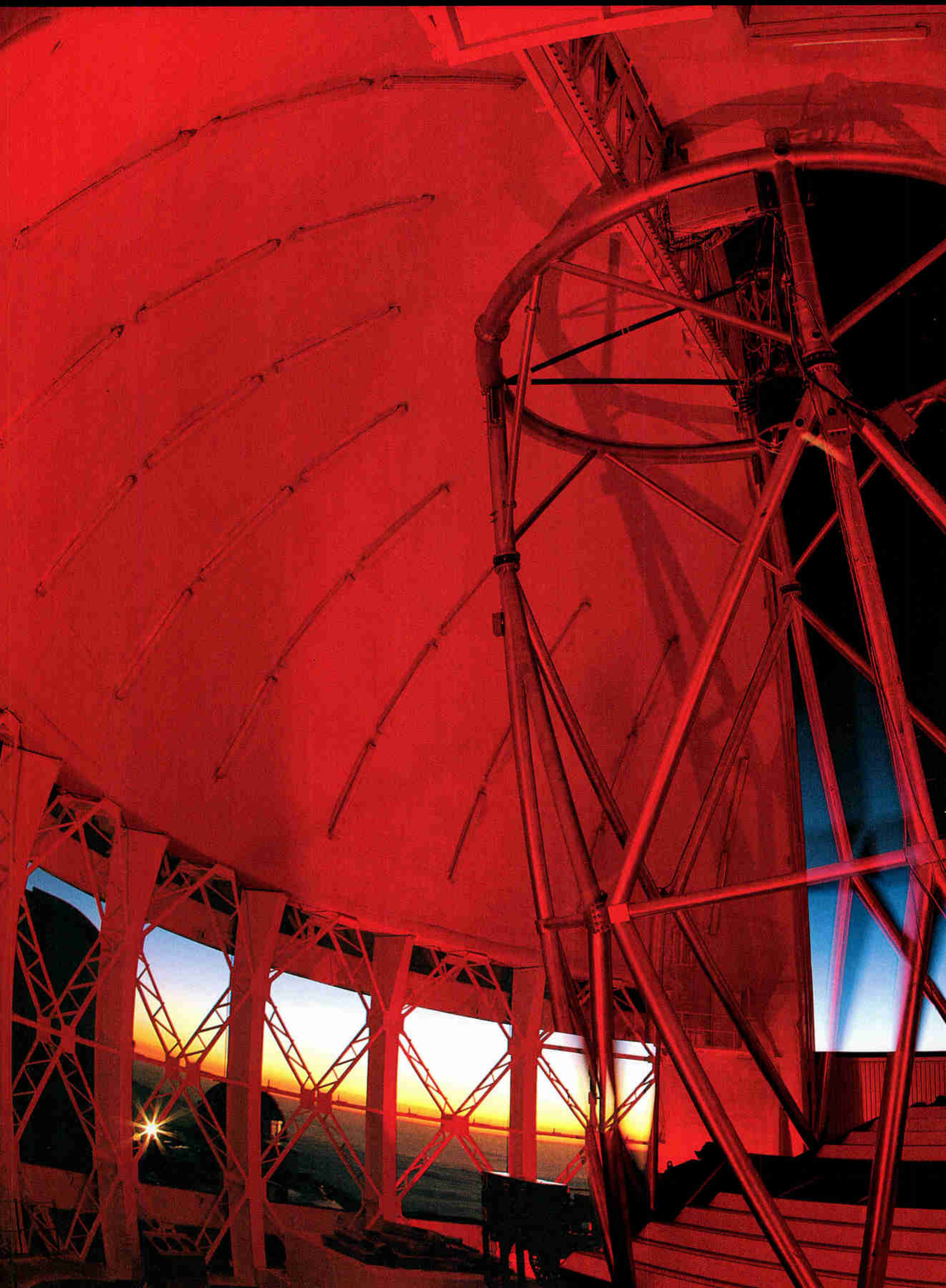
Once they had selected a few distant objects, Malkan and Teplitz exchanged instructions and information with Puniwai in subdued tones as if the three were working elbow to elbow. In actuality the astronomers were sitting in a comfortable control room with the normal quota of oxygen down in the balmy village of Waimea 48 miles away, communicating with Puniwai via live two-way audiovisual hookup—a growing trend in astronomy. Those who work at the summit, Puniwai says, tend to be "more irritable, and sometimes they have trouble making a decision." He himself suffers from an occasional headache and keeps a binder of notes as a memory backup.

In the end Malkan and Teplitz salvaged at least eight hours of observing time and, by covering unexpected regions of the sky, strengthened their study. In the hours before dawn they also managed to train the telescope on a prodigious burst of gamma rays detected a few days earlier from an unknown source most of the way across the observable cosmos. Astronomers around the world were scrambling at the same time to help record its fast-fading glow. Malkan and Teplitz came away with valuable data about the enigmatic event, which turned out to be the most powerful explosion ever measured.

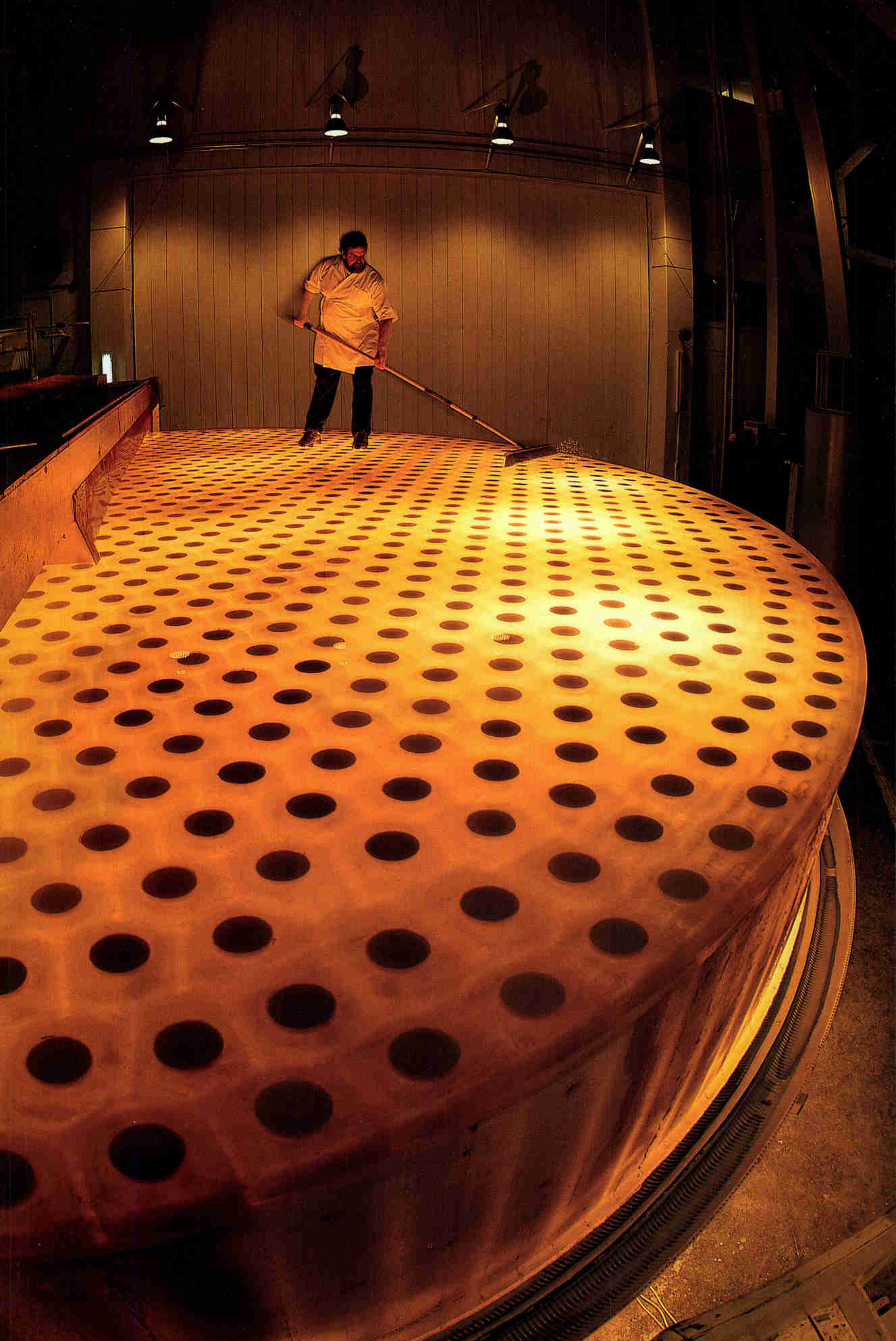
THE SUN'S LIGHT—traveling at 186,000 miles per second—takes eight minutes to reach us from about 93 million miles away. So we see it as it existed eight minutes ago. Modern telescopes can collect light that has traveled for 25,000 years from the center of our galaxy, indeed, light that has traveled several thousand million years across time and space. Scientists hope eventually to witness the epoch when the first shining stars and galaxies emerged from the primordial gloom.

Cosmic exploration has taken on an air of industrial muscularity as competition builds among larger and fancier machines—and as European

VENUS AND JUPITER pass just a degree or so from each other through the slit of Mauna Kea's new Gemini North telescope, so named because it will be teamed with a nearly identical telescope 6,600 miles to the southeast, in Chile. Telescope-dome designers have

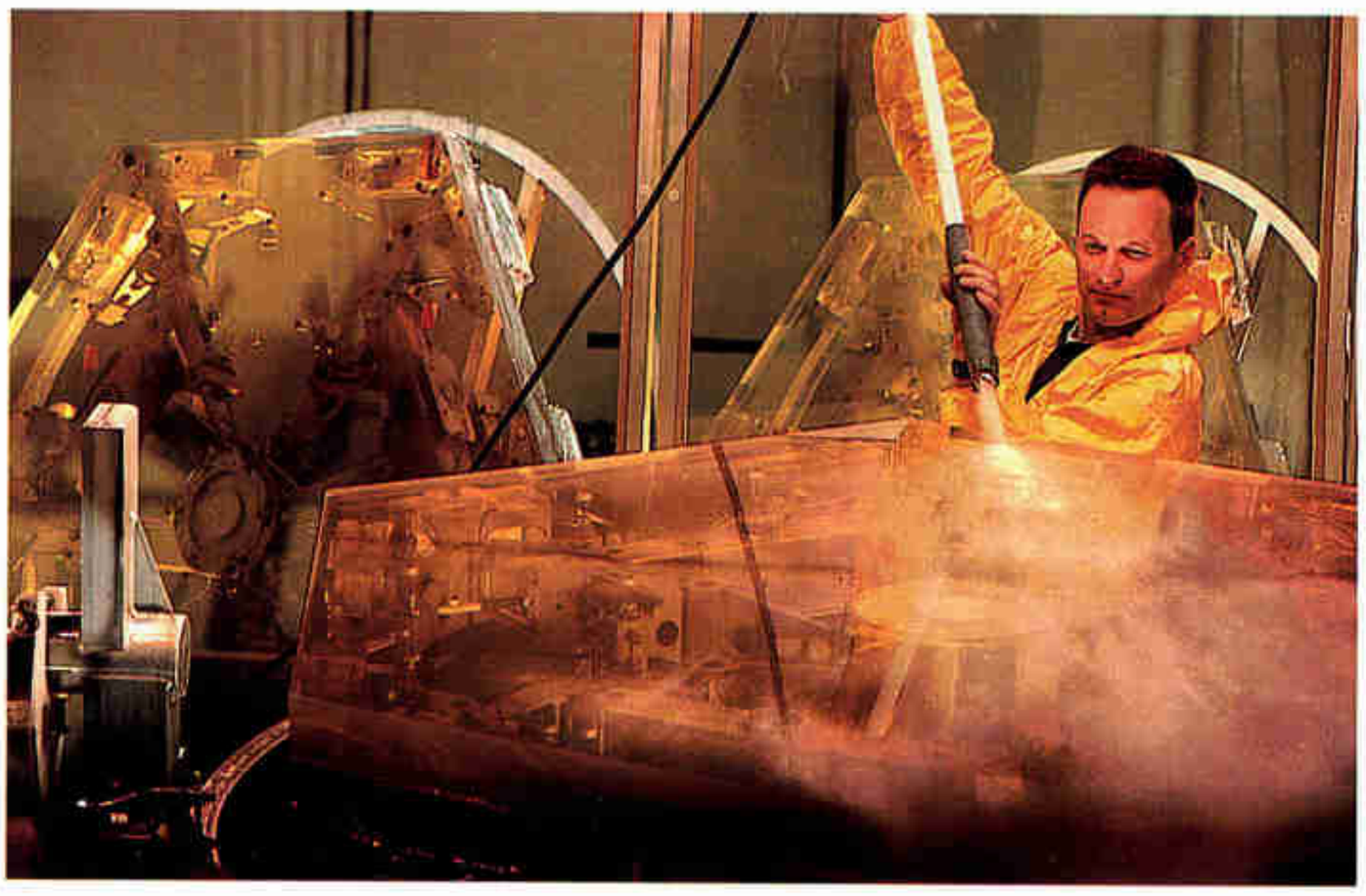


long battled the shimmer that occurs when air temperatures inside and outside a dome differ. The Gemini North dome walls separate to reveal a latticework of air vents near its base. As air moves through, temperatures in and around the dome quickly equalize.



facilities begin to surpass American ones. Modern astronomers are no longer limited to the narrow band of light visible to human eyes or trapped at the bottom of an ocean of atmosphere that either bends or blocks electromagnetic radiation. They can—with continent-spanning strings of linked radio telescopes and ever more sophisticated observatories in space—view virtually the entire rainbow of colors emitted by objects in the cosmos.

Astronomers on both sides of the Atlantic are researching technologies for successors to NASA's Hubble Space Telescope, launched in 1990. Hubble has churned out discoveries and dazzling images, ranging from faint, remote objects to the planets in our own family; captured evidence that black holes really do exist; zeroed in on the age of the universe. The massive Compton Gamma Ray Observatory, the Rossi X-Ray Timing Explorer, the ROSAT x-ray telescope, and a flotilla of other spaceborne instruments have begun to unveil some of the most energetic events in the cosmos. Infrared observing, boosted by a revolution in its technologies, is coming into its own on the ground and in space as a means of studying distant, primeval objects, star-forming regions, and other remote phenomena.



HONEYCOMBED to reduce weight, a record 8.4-meter mirror (opposite) is ground at Arizona's Steward Observatory Mirror Lab for the Large Binocular Telescope on Mount Graham. In Hawaii one of Keck's mirror segments (above) is cleaned with carbon dioxide snow before receiving a new reflective aluminum coating.

Work is under way to link Keck I to Keck II, its twin at the opposite end of the corridor, creating a telescope with resolving power equal to that of a single, whopping 85-meter-diameter mirror. Along with the Kecks atop Mauna Kea are ten more facilities, making the mountaintop a leading international observing enclave. On other prominences, notably in the Chilean Andes, a similar pattern exists.

One of the most important developments in ground-based astronomy is under way at Apache Point Observatory in southern New Mexico, where astronomers are testing and calibrating the components of the Sloan Digital Sky Survey, a five-year project described as the most ambitious astronomical survey ever undertaken. It is designed to determine the position, brightness, and color of more than a hundred million celestial objects across one-quarter of the sky and measure the distances to more than a million galaxies and quasars—the brilliant beacons believed to exist where black holes swallow up stars and gas at the center of galaxies. Its legacy, if all goes well, will be the first standardized digital atlas of five-color images of the north celestial sphere.

As recently as the beginning of the 20th century, conventional wisdom still assumed an unchanging, static universe with no beginning, no end. Then in 1916 Albert Einstein, relying on little more than mathematics and his own profound intuition, came up with the essentials of what would be known as the big bang. But Einstein resisted the implications. It was Alexander Friedmann, a Russian mathematician and meteorologist, who followed through and proposed a model of an expanding universe.

A series of empirical discoveries have since supported that vision. Modern cosmology was launched with the first of these discoveries in 1929, when

SURVEYING THE COSMOS, scientists from the international team conducting the Sloan Digital Sky Survey gather at Fermilab, near Chicago. The team will create an unprecedented atlas of more than a hundred million celestial objects, covering one-quarter of the

sky. Still being calibrated, the Sloan telescope has already discovered four of the five most distant quasars ever found as well as a free-floating "methane dwarf," an obscure object that is smaller than a star, larger than a planet.

LEFT TO RIGHT: RICHARD KRON, ELLYNE KINNEY, HEIDI NEWBURG, JEFF HAYNES, JAMES ANNIS, SHU-I WANG, BRIAN YANNY

Edwin P. Hubble, the American astronomer after whom the space telescope is named, claimed that he had discovered that galaxies are moving apart in all directions.

Hubble had gauged the distances to two dozen galaxies, studying a characteristic of their light known as redshift. Compared with laboratory light, the light from these galaxies—when it passed through a prism and was split into a spectrum of colors—was stretched to slightly longer wavelengths, shifting toward the red. He concluded that the more distant galaxies were racing away from Earth faster than bright, nearby ones. The most familiar explanation of redshift is the Doppler effect, which causes a train whistle to deepen as the locomotive hurtles away from the listener. Across cosmic distances, however, redshift represents the stretching of space itself.

Hubble's findings led to a cosmic narrative that has won remarkable acceptance. Yet within the basic theoretical framework the big bang model continues to undergo mind-boggling refinements.

HOUSED in a rolling shed in New Mexico, the Sloan telescope (above) records light with an advanced array of charge-coupled devices. The light can be further analyzed using an aluminum plate (opposite) drilled with holes that match the positions of selected stars, galaxies, and quasars. The plate allows light from 640 objects to be simultaneously fed to two spectrographs via fiber-optic cables.

BIG BANG THEORY holds that everything in the known universe—all time, space, energy, and matter—was once contained in a point of infinite density known as a singularity. Scientists leave the "why" of that state of affairs to priests and poets. But in the next instant, they theorize, this point began expanding madly in size—pinhead, grapefruit, basketball—to a radius expressed in incomprehensibly large numbers.

After the first millisecond the universe was a featureless fireball about 30 million times hotter than the surface of the sun, 50 billion times denser than lead, and, by the age of one second, it had expanded and thinned to 20 light-years. At that time, presumably, the grainy subatomic ingredients of every leaf, worm, star, rock, manhole cover, automobile, cat, dinosaur, running shoe, and every one of us—all entities past and potential—were combined in white-hot, soupy intimacy with all of space. These initial conditions set immutable limits on the density of all matter and determined the course of cosmic evolution.

The big bang expansion is not an explosion in the classic sense, in which objects are flying out through preexisting space like shrapnel. Space itself is expanding, stretching outward where it had not previously extended, sometimes at velocities faster than the speed of light—a limit that applies to light and other signals but not to space.

The rate at which the universe and all its objects are moving apart—called the Hubble constant—is one of the most important numbers in science. It is expressed in kilometers per second per million light-years (velocity divided by distance). Understanding that number, cosmologists suggest, is key to understanding the natural order of things. The number depends on the amount of "stuff" in the universe, its character, and the degree to which its gravitational forces are retarding the expansion. Those factors in turn affect other events. By tracking the expansion backward, like rewinding a videotape, scientists have sought to define the age, shape, and scale of the universe.

DESERT SENTINELS, the four squared-off domes of the Very Large Telescope (VLT) array have risen on a leveled-off mountaintop on Cerro Paranal in northern Chile. Operated by the European Southern Observatory, two of the four telescopes, all of which will

eventually work in unison to create images of remarkable sharpness, are already on line. Low humidity and less than an inch of annual rainfall create some of the best telescope "seeing" conditions on Earth for capturing the faint light from distant objects.

COSMOLOGISTS PORTRAY THE UNIVERSE geometrically in terms of curving lines. Based on Einstein's theories of gravity and the curvature of space–time, they propose three possibilities: a "closed" spherical universe, in which gravity would eventually halt the expansion and draw everything together again in a flaming "big crunch"; an "open," or saddle-shaped, universe, in which there is so little gravity that the outward expansion goes on forever; and a "flat" universe—or a plane—in which the cosmos coasts between the other two possibilities, slowing but never halting. Conventional wisdom holds that the cosmic expansion must be decelerating as gravity exerts its pull, just enough to create a flat universe. But recent observations have threatened to overthrow that view.

The expanding fireball required perhaps 300,000 years to cool and thin out enough to become transparent to light. Then suddenly, as if a fog had lifted, electromagnetic energy was set free to go traveling through the cosmos. According to Chris Impey, a cosmologist at the University of Arizona, that primordial background radiation is today "streaming through our hair" from a time when one part of the universe was separating from another at 50 times the velocity of light. About one percent of the flickering specks seen in the static of a TV screen are triggered by waves of this light. The existence of this cooled and diluted afterglow of creation has provided a strong pillar of evidence for big bang theory to rest upon.

EUROPEAN SOUTHERN OBSERVATORY

Two Bell Telephone Laboratories scientists, Arno Penzias and Robert Wilson, were the first to stumble on this electromagnetic energy in 1964-65, reporting that their experimental radio antenna was picking up microwaves from all directions in the sky. Then, in a meeting of the American Astronomical Society in 1990, a team led by John Mather of NASA's Goddard Space Flight Center announced findings from the Cosmic Background Explorer (COBE) spacecraft that confirmed beyond doubt the nature of the radiation.

For cosmologists the microwave background radiation serves as a stable reference point—the "rest frame" in a cosmos in which everything is in relative motion. Earth orbits the sun at 67,000 miles an hour. The sun travels around the Milky Way once every 225 million years. The Milky Way is falling toward Andromeda, and both are feeling the tug of the great Virgo cluster 50 million light-years away, and so on.

With the existence of this radiation established, Mather's team pushed COBE's sensitivity to its limits and produced an all-sky map that revealed the faint beginnings of clumpiness in the primordial cosmos that had been, to that point, featureless. These small ripples of increased density detected amid the expanding particle soup presumably represented the beginnings of a reverse gravitational snowball effect, in which some regions lagged behind the overall expansion as they pulled in extra mass. This process produced the architecture of the modern universe—at least a hundred billion galaxies congregating in giant clusters and "walls" around great yawning voids. Spacecraft with instruments ten times as sensitive are being designed

by NASA and the European Space Agency to probe these areas in detail.

No one yet knows how or when the first stars and galaxies began to form in the universe. But astronomers have begun to see back to a time when the universe appears more chaotic and violent, afloat with strange, glowing bits and fragments. They can see quasars, the most luminous objects known in the universe. These objects are believed to be powered by black holes, "places where space itself has been punctured by some colossal collapse," in the words of Martin Rees, Great Britain's Astronomer Royal.

The "ecosystems" of shining galaxies—specifically the thermonuclear processes and explosive death spasms of their stars—are now known to have forged the heavier elements necessary for complexity and life itself. In other words, we are made from the ashes of stellar death. Some scientists have whimsically imagined the meanderings of a single carbon atom, released in the explosive death throes of a star, drifting for eons across intergalactic space, landing in the gas disk that eventually formed Earth, becoming chemically altered, and finally being inserted into a chain of life as part of a nerve cell that guides a human hand to write about it.

EARLY IMAGES from the VLT, spectacular as they are, merely hint at the clarity the instrument will achieve after its third and fourth units—and three smaller telescopes—become operational within the next several years. The facility is expected to yield images of intricate structures within galaxies. One of the earliest images from the first unit, named Antu after the sun god of Chile's Mapuche Indians, was this view of the spiral galaxy NGC 2997 in the southern constellation Antlia.

WHILE THE BASIC FRAMEWORK of the big bang model has achieved wide acceptance, the view of its shortcomings has grown more sophisticated. As Rees has cautioned, "Our present satisfaction may reflect the paucity of the data rather than the excellence of the theory." As the potential for actually obtaining answers has improved, the questions have evolved through the "whats" and "wheres" to the "hows" and "whys." How did the universe go from simple and smooth to lumpy and complex? Why is it so perfectly balanced gravitationally that it neither flew apart nor crunched back together before the first star or galaxy could form? (This degree of balance has been likened to that of a pencil standing upright on its point. Any tipping at all and it would immediately fall all the way over in one direction or another.) And why does the universe look so much the same over vast distances?

Scientists acknowledge that they have no way of proving any theories about what happened less than .0000000000000000000000000000000000000001 of a second after the bang began. Known as Planck time, or 10 to the minus 43, this is the first fraction of a second in which the laws of known physics apply. Scientists searching for a "theory of everything" have been probing as close as possible to that genesis moment.

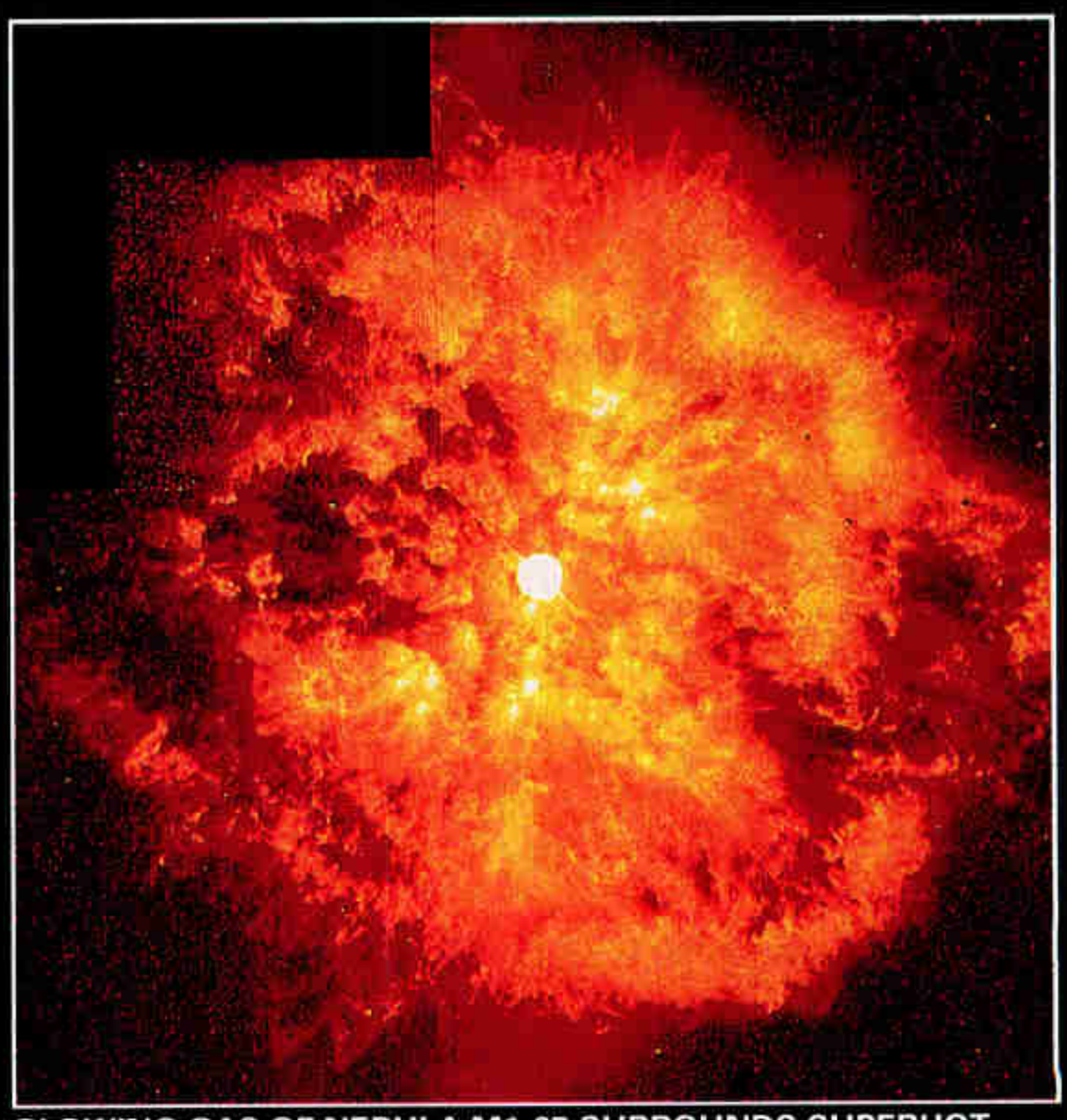
Enter "inflation," a theoretical solution that solves a lot of problems for cosmologists. Derived from quantum theory—the study of subatomic particles—it was proposed in 1980. One of its key proponents, Alan Guth of the Massachusetts Institute of Technology, has described it as "the ultimate free lunch." In essence, inflation theory proposes that in the initial bazillionth of a second, the universe underwent a onetime burp, ballooning exponentially (2, 4, 8, 16, etc.) in diameter before settling into the linear expansion (2, 3, 4, 5, etc.) that we see today. In a fraction of an eye blink, according to Andrei Linde, a Stanford University physicist, a microscopic speck would have grown to an expanse more than a hundred billion light-years across. Inflation allows the universe to be incomprehensibly vast.

The implications are in every sense gargantuan. By permitting such a vast space–time geometry, inflation explains how the expanding universe can appear to be flat—and so finely balanced that it can coast toward infinity without either flying apart or collapsing back in on itself.

Until the mid-1990s the data on the rate *(Continued on page 32)*

LIKE EXHAUST FROM JET ENGINES, GAS AND DUST OF THE NEBULA M2-9 RUSH FROM A DYING STAR AT MORE THAN 100 MILES A SECOND. BRUCE BALICK AND NASA

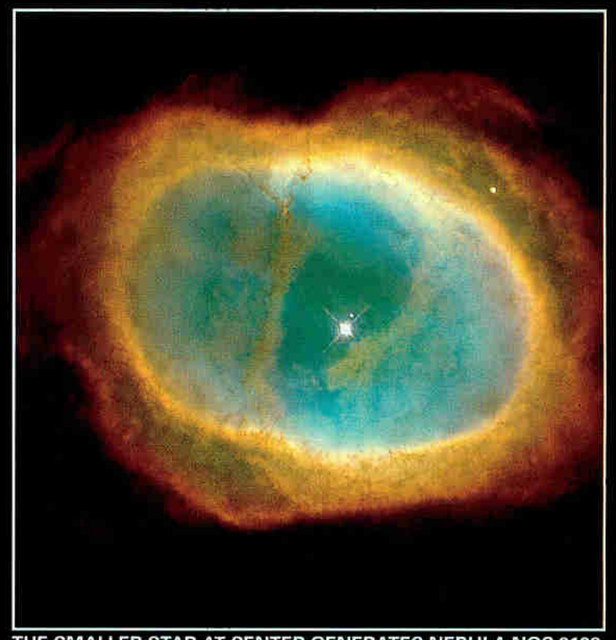
STELLAR WIND SHAPES NGC 7635, A BUBBLE NEBULA OF GAS AND DUST. HUBBLE HERITAGE TEAM



GLOWING GAS OF NEBULA M1-67 SURROUNDS SUPERHOT STAR WR124. YVES GROSDIDIER AND NASA

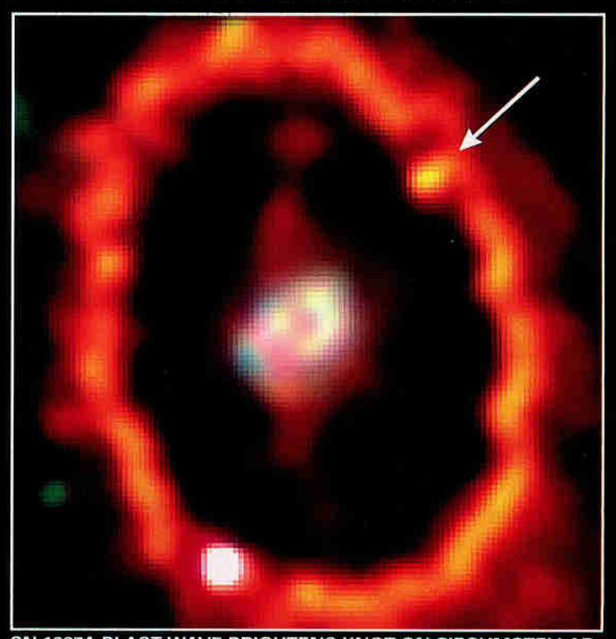
Hubble's Universe

For nearly a decade the Hubble Space Telescope has dazzled with images like these. The telescope recently completed one of the tasks for which it was created and named: measuring the Hubble constant, the rate at which the universe is expanding. Distant galaxies are racing away from us more quickly than nearby ones. By studying the light of some 800 rare pulsating stars, a team recently calculated that for every 3.26 million light-years distant an object is from Earth, it is moving away 160,000 miles an hour faster. Such knowledge helps to establish the age and fate of the universe.



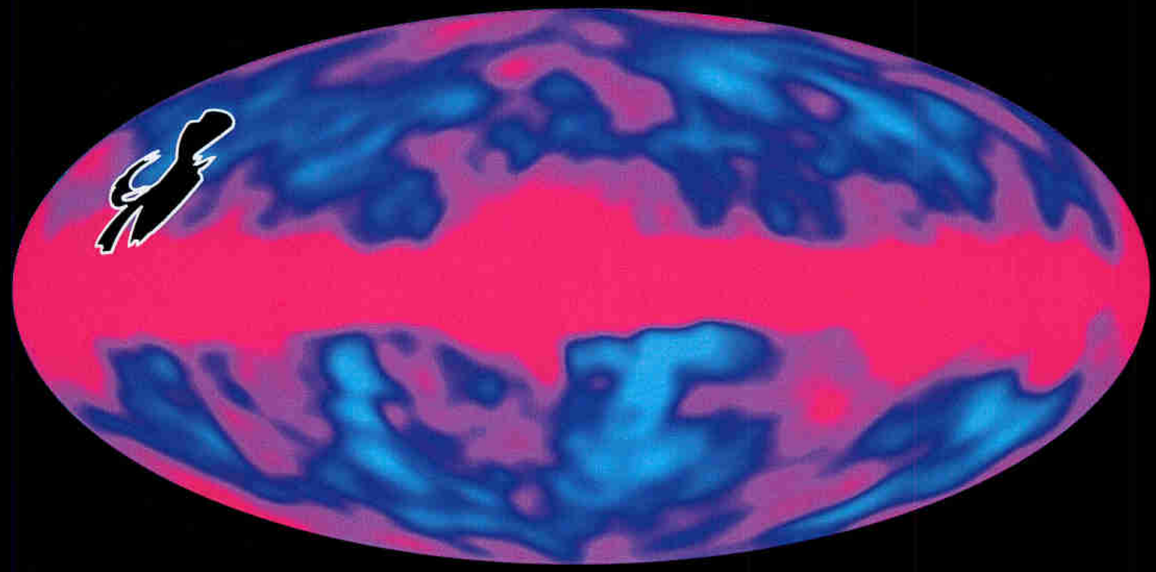
THE SMALLER STAR AT CENTER GENERATES NEBULA NGC 3132.
HUBBLE HERITAGE TEAM, SPACE TELESCOPE SCIENCE INSTITUTE, AND NASA

A BLACK HOLE MAY LIE AT THE HEART OF GALAXY NGC 7742.
HUBBLE HERITAGE TEAM



SN 1987A BLAST WAVE BRIGHTENS KNOT ON CIRCUMSTELLAR RING. ROBERT KIRSHNER, SPACE TELESCOPE SCIENCE INSTITUTE, AND NASA

Mapping the Universe

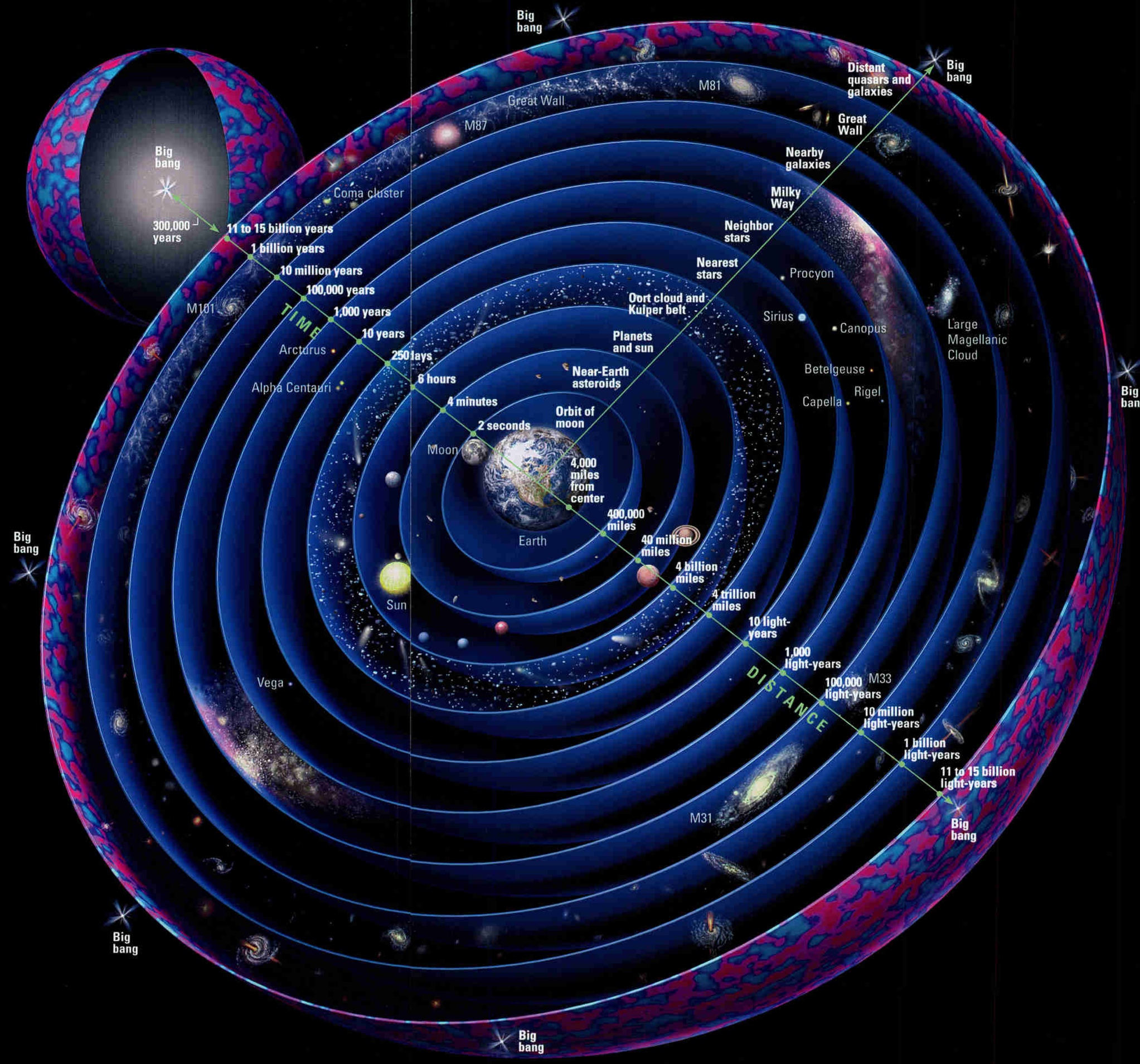


The closest thing we have to a baby picture of the universe is the blob-filled image above, the microwave glow that permeates space. Orbiting above the atmosphere, the Cosmic Background Explorer (COBE) detected patterns of "fossil radiation" that date back to 300,000 years or so after the big bang, a time before galaxies began to form. Radiation slightly warmer than the 2.7-kelvin average is shown in red, cooler in blue. The band across the middle depicts emissions from our own galaxy. It is a remarkable picture but fuzzy: COBE could resolve only areas larger than 15 times the size of the full moon. Scientists are now studying the background with devices that have much sharper resolution. One study, called QMAP, launched a sensor on two high-altitude balloon flights. From their data, scientists developed an image (left) that yields a much more detailed look at the patterns of heat in one area of the infant universe. "From this information we want to learn what the universe is made up of and what it's shaped like," says Max Tegmark of the University of Pennsylvania, a QMAP team member. "We don't have the answers yet, but we now know that the data exist to answer the big questions."

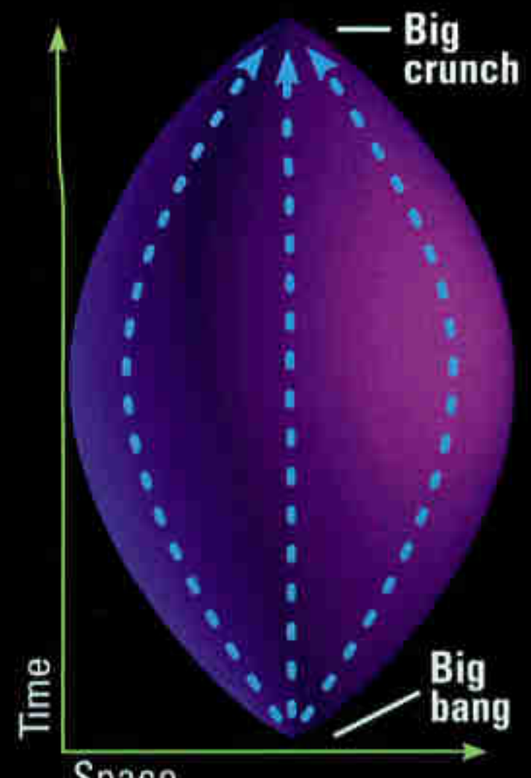
NASA/COBE TEAM, NSSDC (TOP); MAX TEGMARK AND ANGELICA DE OLIVEIRA-COSTA, QMAP TEAM

The view from Earth

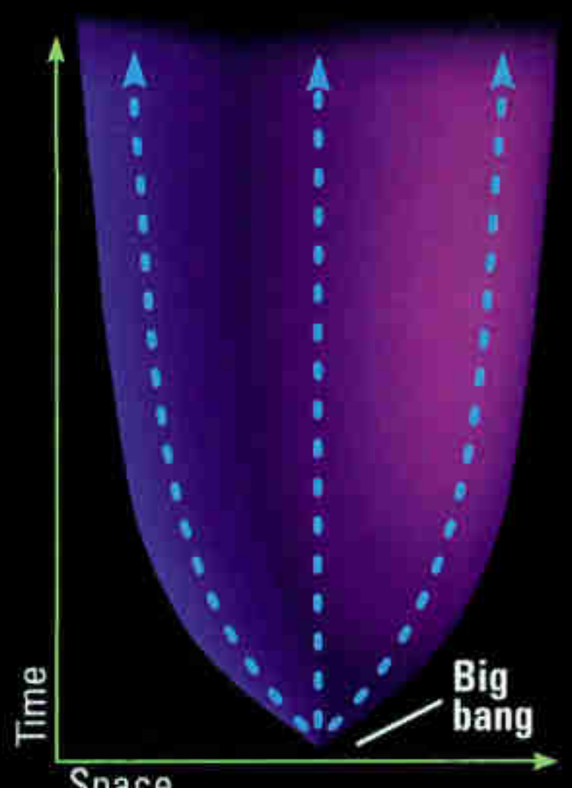
The ancients had it wrong: The Earth is not the center of the universe. But the Earth *is* at the center of the part of the universe that we can see. A being on a planet orbiting, say, a star in the galaxy M87 would see a different part of the universe, one centered on him. In a universe thought to be 11 to 15 billion years old, we can see out a distance of 11 to 15 billion light-years in all directions. From the Earth's viewpoint at midnight GMT, January 1, 2000, the elements of the cosmos will appear as they do here (right). Distances are not shown to scale but increase dramatically as they become more remote. The farther out we look, the farther back in time we see. Light takes 50 million years to arrive from M87, so we see it as it appeared 50 million years ago. The limit of our view is the time when the universe emerged from a state of hot plasma and became transparent, some 300,000 years after the big bang. That period is seen as the glow of the microwave background (shown in red and blue). If we could look beyond that veil, we would see—according to the standard models—the big bang itself, no matter in which direction we looked. The portion of the big bang we could then observe would be a point of infinitesimal size and infinite density.



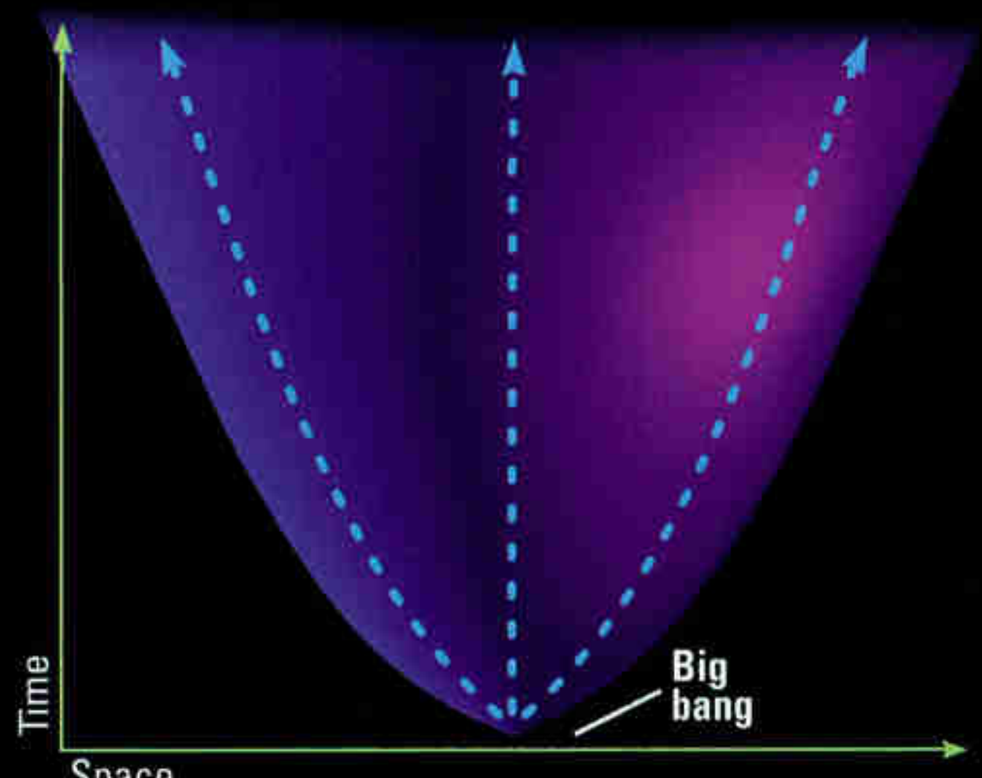
ART BY CHRISTOPHER SLOAN, NGS STAFF, AND DAVID FIERSTEIN. SOURCES: RICHARD GOTT, JEFF HAYES, ROBERT OSSERMAN, JEFF WEEKS (ABOVE); RICHARD GOTT, LI-XIN LI (BOTTOM RIGHT)



CLOSED UNIVERSE
With density above a critical level, the universe eventually collapses on itself.



FLAT UNIVERSE
At critical density, the universe expands without end, but gravity slows expansion over time.



OPEN UNIVERSE
At less than critical density, the universe expands forever, with galaxies continuing to recede at nearly their current rate.

The fate of the universe

Scientists exploring the ultimate fate of the universe usually start with three standard models.

In the high-density closed universe model (above left) the number of galaxies is finite, and eventually gravity will pull all matter back together in a "big crunch." The flat universe (above center) starts like the closed model, but because it is less dense, it expands forever. It has an infinite number of galaxies. With relatively little density to slow it down, the open universe (above right) grows faster than a flat one. It also expands forever and has an infinite number of galaxies.

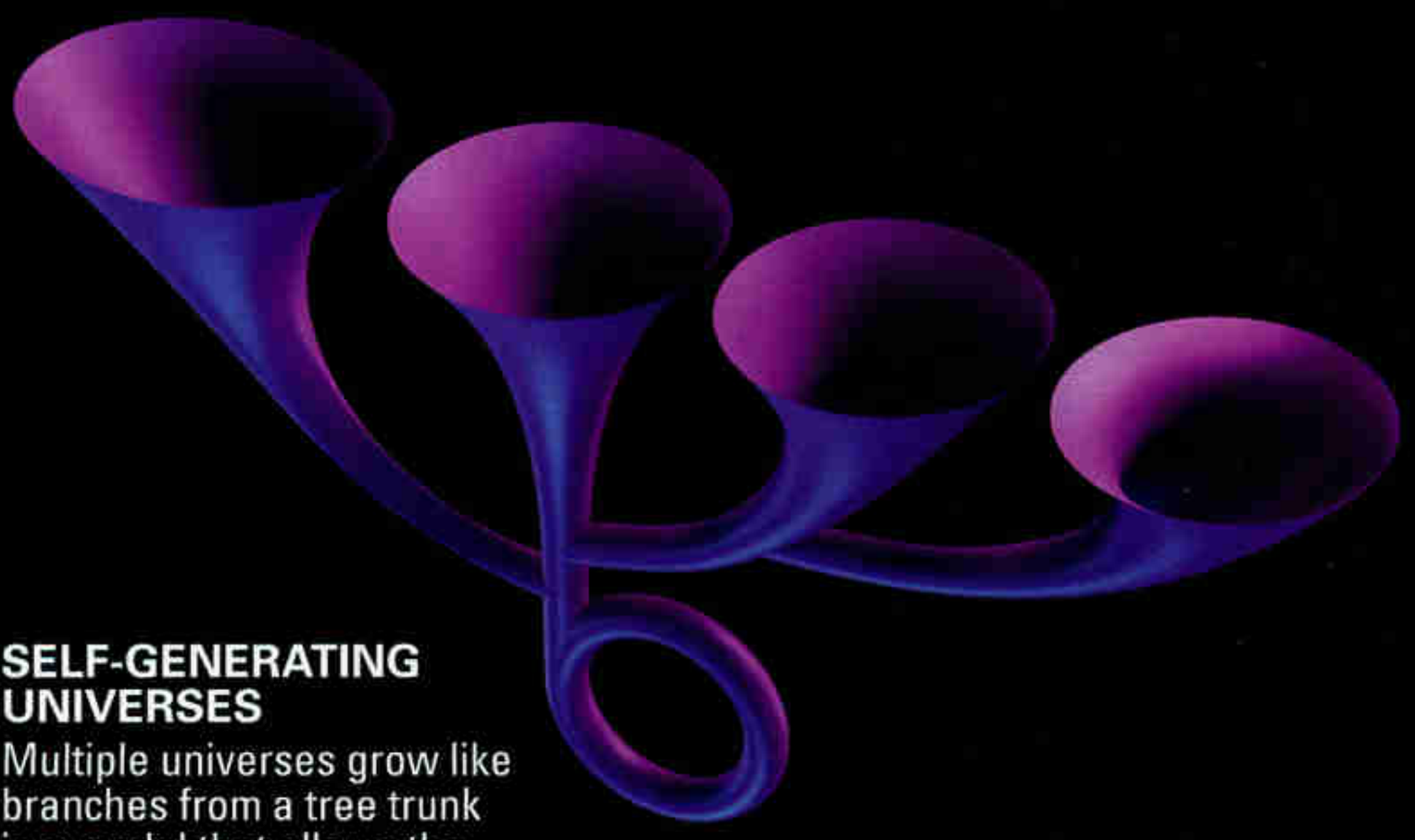
Many scientists lean toward the flat model, but refinements are under way as evidence mounts that a mysterious energy in the vacuum of space is accelerating rather than slowing expansion.

But how did the universe start?

Insisting that the cosmic background is too evenly distributed to have resulted from a simple explosion, physicist Alan Guth of the Massachusetts Institute of Technology suggests instead that zones of space smaller than an atom can burst into a period of propelled expansion and matter creation he calls inflation.

Instead of a single expanding universe, Stanford University physicist Andrei Linde advances the notion that chaotic inflation gives rise to multiple universes eternally producing new universes. The origin is pushed to an indefinite past.

What was the initiating event? Richard Gott and Li-Xin Li of Princeton University propose adding a loop to the bottom of the multiple universe model (below), enabling the universe, in Gott's words, "to become its own mother."



SELF-GENERATING UNIVERSES
Multiple universes grow like branches from a tree trunk in a model that allows the universe to create itself.

(Continued from page 25)

of cosmic expansion were so uncertain that the best estimates of the age of the universe stood at between 10 and 20 billion years. Then in 1994 a team led by Wendy Freedman of the Carnegie Observatories in Pasadena, California, startled colleagues with preliminary findings from the Hubble Space Telescope indicating that the universe was astonishingly young—between just 8 and 12 billion years old. This suggested a universe younger than some of its own offspring—its oldest stars, their ages based on the known physics of stellar evolution. Freedman's colleague down the hall, the legendary cosmologist Allan Sandage, led a rival camp whose evidence has continued to support an older universe. Their dueling with data has provided a high-profile demonstration of the process by which scientists converge toward truth. Recently released numbers from the Freedman team, along with those defining the ages of the oldest stars, are pointing toward a universe about 12 billion years old.

The research recently took a surprising turn, however. Answering fundamental cosmic questions depends on correct measurements across great cosmic distances—not easy to achieve. Basically, scientists need to be able to determine whether they are observing a dim object close by or a bright object far away. For this Freedman, Sandage, and other astronomers have sought out extremely bright stars and other objects to serve as "standard candles" whose intrinsic brightness, or "wattage," can be measured.

GOING DEEP, the Hubble Space Telescope looked at a spot near the south celestial pole for a ten-day time exposure (opposite). The image shows thousands of never-before-seen galaxies along a corridor nearly to the dawn of time. Using ground-based Southern Hemisphere telescopes, astronomers will calculate distances to a number of the brightest galaxies discovered in the image.

Such an object must be luminous enough to be detected across billions of light-years. A certain type of supernova—an exploding star—has begun to pay off with spectacular results. Known as Type Ia, it reliably spews out gas and energy in a predictable pattern: The bigger explosions last longer than fainter ones. By monitoring how long explosions last, astronomers can determine their inherent brightness to within 12 percent. Somewhere in a typical galaxy one of these telltale explosions flares about once every 300 years. By monitoring a few thousand galaxies, then, astronomers can expect to see at least one of these supernovae a month.

A couple of international teams have led the effort to comb the heavens for these events—one organized by Saul Perlmutter of Lawrence Berkeley National Laboratory in Berkeley, California, and another led by Brian P. Schmidt of the Australian National University. The work is labor-intensive, requiring researchers to conduct rapid eyeball analysis of hundreds of images. At times, according to Robert Kirshner, a Harvard astronomer, and colleague Nicholas Suntzeff, the Cerro Tololo Inter-American Observatory in Chile, where much of this work is done, "becomes a sweatshop of astronomers and visiting students, who work around the clock for days at a stretch, sustained by enthusiasm and Chilean pizza."

The teams work with large electronic light detectors attached to giant telescopes that can, in a single exposure of an area about the size of Earth's moon, produce a picture of 5,000 galaxies in ten minutes. In before-and-after images of the same patch of sky taken a few weeks apart, computers count the number of photons in each picture, subtracting the total in one image from the total in the other. Significant change in the photon count points researchers to the faint new smudge—often too subtle for the human eye to detect unaided—that represents a faraway supernova. Keck I and II on Mauna Kea, along with the Hubble Space Telescope, perform the final refinements.

In studies of several dozen supernovae four billion to seven billion light-years away, the teams were astonished to find the explosions on average 25 percent dimmer than expected. The researchers have concluded, and a growing number of other scientists agree, that the surprising faintness is caused by

an unexpected property of the cosmos—that it was expanding more slowly in the past. Or in other words, the expansion is accelerating. Skeptics suggest the dimming could merely be the result of intervening cosmic dust or other distortions or of some intrinsic change in the nature of supernovae over the eons. But team members say that their own rigorous efforts to knock their own findings down, based on those same suspicions, have so far proven futile. Their discovery was named *Science* magazine's "Breakthrough of the Year" for 1998.

An accelerating expansion would assist in bringing the age of the universe into accord with the ages of its oldest stars: If the universe was expanding more slowly in the past, it took longer to reach its current stage than is implied by measurements of the current expansion rate—and therefore could be older than it looks.

In order to accommodate the new evidence of an accelerating universe, some scientists have turned to a fudge factor known as the cosmological constant. This perennial angel has been invoked over the years to bail out problem equations. A concept that Einstein introduced and later dismissed as a mistake, it proposes an exotic repulsive energy that fills "empty" space, separating objects rather than drawing them together as ordinary gravity does. Scientists who study the smallest units of nature have learned that this vacuum is actually seething with activity at the subatomic levels as particles pop in and out of nothingness. Though these are virtual particles, laboratory experiments have shown that they have real and predictable effects. Such particles may be exerting an influence that accumulates across vast distances in a way that is accelerating the expansion of the universe.

NASA AND ROBERT WILLIAMS, SPACE TELESCOPE SCIENCE INSTITUTE

"The cosmological constant is good news for inflation theorists," says Alan Guth, "since most versions of the inflation theory call for a density of matter and energy that flattens the universe." So far astronomers have not found that much matter, but the invisible energy associated with the cosmological constant could be just what is needed. This energy would allow scientists, in essence, to have their cake and eat it too. Now they can have a low-density universe that, thanks to the mysterious energy in the vacuum, is also flat and effectively eternal. The equations work out.

THE NEW FINDINGS, though, are tied up with another frustration. Scientists have long admitted, with some chagrin, that they are unable to locate most of the mass in the universe—the sources of gravity. The evidence for this missing mass comes from two sources: One is the actual observed motions of galaxies, gases, and stars, which would fly apart from each other if there were not some influence much more powerful than their own gravity holding them together. The other comes from inflation theory and its requirement for just the density needed to keep the universe flat.

Scientists have looked high and low for the missing mass. Is it in ghostly dark galaxies, roving collapsed objects, strange particles of energy such as the

ALL EARS, the Very Large Array (VLA) radio telescope near Socorro, New Mexico, uses 27 movable antennas to gather faint radio signals from across the cosmos. Since coming on line in 1980, the National Science Foundation facility has made detailed images of a

host of distant natural phenomena that emit strong radio waves—the birth of stars, galactic collisions, and the suspected black hole at the center of the Milky Way—as well as the sun and the planets of our own solar system.

neutrino? An international collaboration of physicists, using the underground Super-Kamiokande detector in Japan, last year shook up their field with evidence that the neutrino, previously thought to have no mass at all, actually weighs about one ten-millionth the mass of an electron. Since the cosmos is aswarm with 1,800 neutrinos per cubic inch—flying unnoticed through our bodies and all other matter and through seemingly empty voids of interstellar space—this is a noteworthy contribution to the total cosmic mass.

Accumulating evidence indicates that the total measured density of all radiation, normal matter, neutrinos, and other bizarre stuff accounts for perhaps 10 to 30 percent of the expected density. In short, there seems to be abundant evidence that, even including the potential quantities of mysterious invisible dark matter, there is not enough to flatten the universe. Again, this requires either revisions in the theory or the aid of the cosmological constant that fills empty space and multiplies its repulsive influence across vast distances. Some scientists, preferring the former alternative, are rummaging around in the early moments of the big bang in search of a different way out of the confusion.

"It's sort of like we're brushing our ignorance under the rug of the very early universe," says Chris Impey.

AS OUR IMAGE OF THE UNIVERSE has exploded, humanity has lost the ancient conviction that its role must be all-important. We know now that our planet is an insignificant speck circling an ordinary star, far out on a spiral arm of the Milky Way galaxy, which is an ordinary congress of a few hundred billion stars among at least a hundred billion galaxies.

We are still the only intelligent life we know of anywhere. But now humankind has taken a dramatic leap toward another possible demotion. Until a few years ago the search for worlds beyond the sun was notable primarily for a series of frustrated hopes and claims that collapsed under scrutiny. Then in October 1995 a Swiss team led by Michel Mayor became the first to report the valid detection of a planet around a sunlike star. The scientific community, burned so often, remained skeptical until a team of young, determined Americans led by Geoff Marcy confirmed the Swiss discovery using a precise new technique that has revolutionized the field.

As of April this year the growing number of planet-hunting teams had reported a total of 20 worlds detected in orbit around sunlike stars outside our solar system. This number includes the long-awaited discovery, reported in mid-April, of the first multiplanet system ever detected around a normal star. The tally has grown large enough to reveal unexpected statistical patterns that raise questions about the processes that create and destroy worlds and about the prospects for other life-harboring planets like Earth.

REFLECTING on Earth's origins at the Keck telescopes, astronomers Geoff Marcy, at right, and Paul Butler have led the way in finding planets orbiting distant stars. In 1996 they discovered a planet orbiting the sunlike star Upsilon Andromedae by studying changes in the star's velocity. Recently they found two more planets orbiting Upsilon Andromedae—the first evidence of a solar system beyond our own.

For example, existing techniques can detect only larger planets—on the scale of our own Jupiter. But not one of the extrasolar Jupiters behaves like our Jupiter. They all follow paths much closer to their parent stars and, in most cases, paths that are much more eccentric, or egg-shaped. Scientists say these giants might have swept away any Earth-like siblings early in their development. Yet most sunlike stars appear not to have these marauding giants. More data, along with improved observing techniques, should reveal ever smaller planets, and families of planets that more closely resemble Earth's.

"I feel a personal yearning, at a gut level I can't explain, to understand why this precious little blue globe is the way it is," says Marcy, who, along with colleagues Paul Butler and Debra Fischer, forms the groundbreaking team that has discovered most of the known extrasolar worlds.

Marcy is another veteran of oxygen-deprived nights atop Mauna Kea. But on this particular day he is on home ground, navigating his venerable Honda Civic, festooned with duct tape to hold together a crimped fender, through a schedule that includes teaching a lively morning class on Newtonian celestial mechanics at San Francisco State University, playing tennis, being

LOOKING FOR GRAVITATIONAL WAVES, the Laser Interferometer Gravitational-Wave Observatory will try to detect ripples in space–time produced by explosions in the distant universe. Einstein predicted such waves, suggested by this time exposure, but they have

yet to be directly detected. Aiming lasers down long tunnels, LIGO facilities near Livingston, Louisiana (below), and Richland, Washington, hope to simultaneously detect the wave forces moving mirrors as little as one-billionth the diameter of a hydrogen atom.

interviewed at the California Academy of Sciences planetarium in Golden Gate Park, and then crossing the Bay Bridge to his other office at the University of California at Berkeley. He works there until about midnight, checking data and calling up computer analyses, watching as the latest discoveries slowly take shape on his computer screen. Along with the thick research catalogs and books on his shelves is a copy of the Little Golden Book of planets.

The data that Marcy, Butler, and Fischer work with do not permit an image of a planet itself, nor do they reveal anything about its surface composition. Looking for a planet around a blazing star light-years distant, even with powerful detectors, is like trying to spot a lightning bug circling in the light of a high-powered spotlight a thousand miles away.

The unique technique that Marcy and Butler developed over an eight-year period uses specially refined hardware and software to effectively chop up the light from stars, looking for the tiny wobble caused in a star when it is tugged by the gravity of one or more circling planets. But as recently as the late 1980s their efforts were disdained by colleagues. Painfully mindful of the embarrassing retractions that had plagued the field, Marcy says that when he and Butler first began to announce results, he felt a mix of "enormous euphoria" combined with "the grotesque fear" that they had blundered—that

STAR TRAILS in a time exposure silhouette an observer in New Mexico. As radio observatories worldwide combine data to create huge virtual telescopes, scientists plan new telescopes for use in Earth orbit and dream of others beyond Mars. This telescopic golden age is yielding answers to ancient questions—and raising new cosmic mysteries.

their findings were "some outgrowth of a hideous flaw in the software."

Now they are confident they can detect changes in velocity in sunlike stars a few hundred light-years away within a margin equal to about human walking speed. They can describe an unseen planet's minimum mass and orbital period. They are working hard to make their data even more precise, and they plan to combine their results with those of other teams using complementary techniques in a way that should help determine a planet's diameter and whether it is a gas ball or something more dense.

ON MARCY'S BLACKBOARD tonight is a smudged chalk chart listing four telescopes—two at Lick Observatory down the coast, Keck I, and a site in Australia—with observing schedules for his team members. All told, these four telescopes are surveying 800 nearby stars, and they have five to ten new planet candidates incubating at any moment. Butler is 7,500 miles away at the Anglo-Australian Observatory, and Fischer is observing at Lick. "We've got a three-ring circus going here," Marcy says, laughing.

With Bach playing softly in the background, he summons up data that have piqued his interest: more than a decade of information about a star called Upsilon Andromedae. The roller-coaster pattern of dots emits a friendly electron glow in the darkened office. There is a curious scatter, though, a second trend emerging. He calls Fischer at Lick. His suspicions will soon be borne out in headlines around the world: There are three planets circling that star. And astronomers would have been delighted simply to find two around any star other than the sun. Up to now, they had detected no more than one.

Over the next decade NASA's Origins program plans to deploy a series of spacecraft that will culminate in a linked set of giant telescope arrays that will try to zero in on sister planets—"blue marbles" like Earth—by detecting the telltale chemical signature of life in those alien atmospheres. These studies could lead to eventual imaging reconnaissance of such worlds.

For now, humanity can bask in its special status as the only life known to be contemplating such questions. Many scientists predict that this distinction, too, will crumble, perhaps in the new century, as they intensify their search for alien signals and Earth-like worlds. But the search for other worlds is not only a quest for kindred intelligence. As Marcy muses, it is also about "the destiny of the human species. Where are we going to be a hundred million years from now? Where will we go, and how will we get there?"

And how will it change who we are? □

Learn how photographer Joe McNally captured the images for this article at *www.nationalgeographic.com/2000/science/universe/.*

The molecule that programs our biological potential, deoxyribonucleic acid, or DNA, is beginning to yield its secrets. As scientists map our genetic universe (right), we look to the promise of curing diseases and solving mysteries of forensics and

SECRETS OF THE GENE

evolution. But advances bring thorny ethical questions. For example, sperm-sorting technology improves parents' chances of choosing a child's sex—pink-marked sperm (background) will produce girls. Are we ready for the gene age?

By JAMES SHREEVE

Photographs by KAREN KASMAUSKI

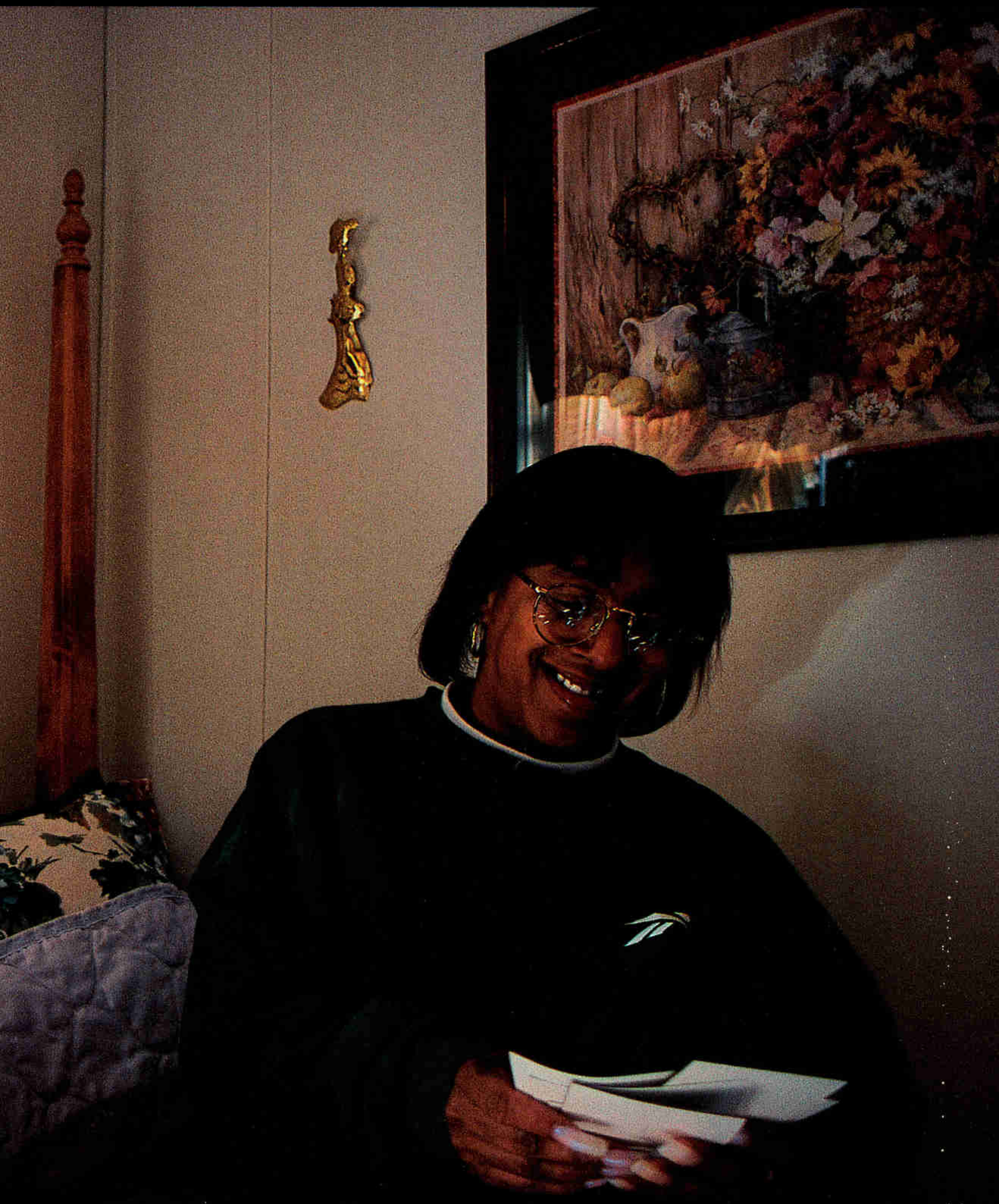
MICROSORT, FAIRFAX, VIRGINIA (BACKGROUND)

SWINE AND SOMETHING MORE, piglets with a human gene are bred to heal at Virginia Tech's Pharmaceutical Engineering Institute. From their genetically altered great-great-grandfather, each pig has inherited the gene that manufactures the protein known as

factor VIII, a clotting agent needed by type A hemophiliacs. When the pigs mature, females will produce the protein in their milk. "Three hundred to six hundred milking sows could meet world demand," says Bill Velander, the institute's director.

"WE THINK THE SAME. We've even bought each other the same birthday cards," says Geraldine Roberson, right, 15 minutes older than her identical twin and genetic double, Christine Taylor. But they're different in some ways. Only Christine suffers from arthritis,

a condition that burdened their father, whose portrait looks over their Rocky Mount, North Carolina, home. What aspects of behavior and disease are inherited? The Carolina African-American Twin Study of Aging hopes to find clues.



SINCE THIS STORY is about the revelation of secrets, it seems fitting to begin in a room within a room within another room. Before passing through to the innermost chamber, I have been told to cover my clothes and shoes with disposable paper garments and my eyes with plastic goggles. I have put on two pairs of surgical gloves. I have been instructed to leave my notebook outside; nothing brought into the room is allowed to come out, so I must take notes on loose sheets of paper and fax them out to a machine down the hall. Such protocols are necessary because the work in this sterile sanctum—the extraction room at a biotech company called Affymetrix in California's Silicon Valley—sometimes means handling blood containing viable HIV and other deadly infectious agents.

The vial of blood in the room today poses no threat of infection to me, because it is my own. What is about to happen is not normal procedure at Affymetrix or anywhere else, at least not yet. I have come here, after sending my blood in advance, to pay witness to my own genetic code in as complete and intimate a form as the current state of biotechnology will allow. Affymetrix designs and manufactures GeneChip arrays—squares of glass smaller than a postage stamp, planted with millions of strands of DNA, like blades of grass. The chips are essentially probes that researchers and pharmaceutical companies can use to dive into the human genetic landscape and come back with a snapshot of some vital part of its terrain. I have asked Affymetrix to test my DNA with a new GeneChip that will take a crude aerial photograph of my entire genome—the complete genetic script I have inherited from my parents. A copy of that script is spooled along the chromosomes inside virtually every one of my trillions of cells.

A technician pipettes a little of my blood into a test tube, then adds a series of chemicals. It is standard procedure for the extraction of DNA from blood, and over quickly. Half an hour later an Affymetrix scientist named Kyle O'Connor presents me with the work in progress: a creamy speck of raw DNA clinging to the bottom of a blue plastic tube.

"Allow me to introduce you to yourself," says Kyle. For a disorienting moment I am not sure which of us he is speaking to. The notion that something as complex as a human being can be distilled into a test tube is of course absurd. Nevertheless, the pale residue in this vial does contain the chemical guidelines that have informed the development of my body and brain from the moment I was conceived. It holds a detailed record of my ancestral past and to an uncertain extent a forecast of my personal future. It is virtually immortal, a thread tying this one life to all life that has ever lived or is yet to live. But it is also the part of my anatomy most unerringly myself. How much do the secrets in that tube affect the way I look and act, how I respond to the world, and how long I will remain a part of it? To what extent am I my genes?

DECODING LIFE: A layer of DNA laced with a chemical marker glows pink under ultraviolet light. Organizations around the world are racing to identify every letter, or nucleotide, in our DNA.

JAMES SHREEVE is working on a book about the race to uncover the human genetic code, to be published by Alfred Knopf. Of the many articles KAREN KASMAUSKI has photographed for NATIONAL GEOGRAPHIC, she found this story the most emotionally challenging. Everyone she met had "strong feelings about this subject because the perception is that genes define us."

Such questions are hardly new; they are the essence of the nature versus nurture debate that has perplexed thinkers for centuries. But now we are on the verge of having finite answers. Without much time to consider the implications, scientists have developed the ability to tap into the code of life and bring its power to bear on our daily lives, the way one might conjure up a spirit to intervene in some earthly affair. This eruption of genetic information is transforming the way medicine is practiced, crimes are solved, and the very nature of life is understood. But its power is frightening too, even to those who understand it best. Who has a right to know the secrets written in our genomes? How much do we want to know ourselves?

"There are a tremendous number of ethical issues involved," says Steve Fodor, Affymetrix's CEO and guiding force. "People are stepping very softly in order not to blunder into an area and do things that are irreversible."

Kyle performs more chemical reactions to purify and amplify the DNA in the tube and then transfers it to the GeneChip. It must incubate overnight before we can see the results.

Driving on the freeway back to my hotel, I think about a billboard I passed on another highway when I began this story months ago. Instead of hawking cigarettes or cars, this billboard promoted paternity testing. Looming over the rush hour traffic, it showed a swarm of giant cartoonlike human sperm swimming on a black background, with the message "Who's the father?" in bold letters. In even bolder letters was a phone number made easy to remember: 1-800-DNA-TYPE.

It is time we all got to know our genomes better—and the powers they possess.

FROM THE DOORWAY, the Eagle pub on Bene't Street in Cambridge looks like any other venerable, exceedingly cozy British drinking establishment. It has the distinction, however, of having once been the haunt of a brilliant, brash young Englishman named Francis Crick and a brilliant, even brasher and younger American named James Watson. On the last day of February in 1953 Crick burst through the doorway where I am now standing and announced to all within earshot that he and Watson had found the secret of life. On a rainy October day almost half a century later it seems worth a side trip in my travels to pay homage. I'm just not sure how to do it.

"So this was Watson and Crick's pub?" I mumble to a fellow at the bar. He shrugs. Never heard of the blokes. For a moment I wonder if I'm in the right exceedingly cozy drinking establishment. But the barkeep has overheard my question.

"Abbot," he says.

"Abbot?"

"That's what they drank. Crick and Watson. Abbot Ale."

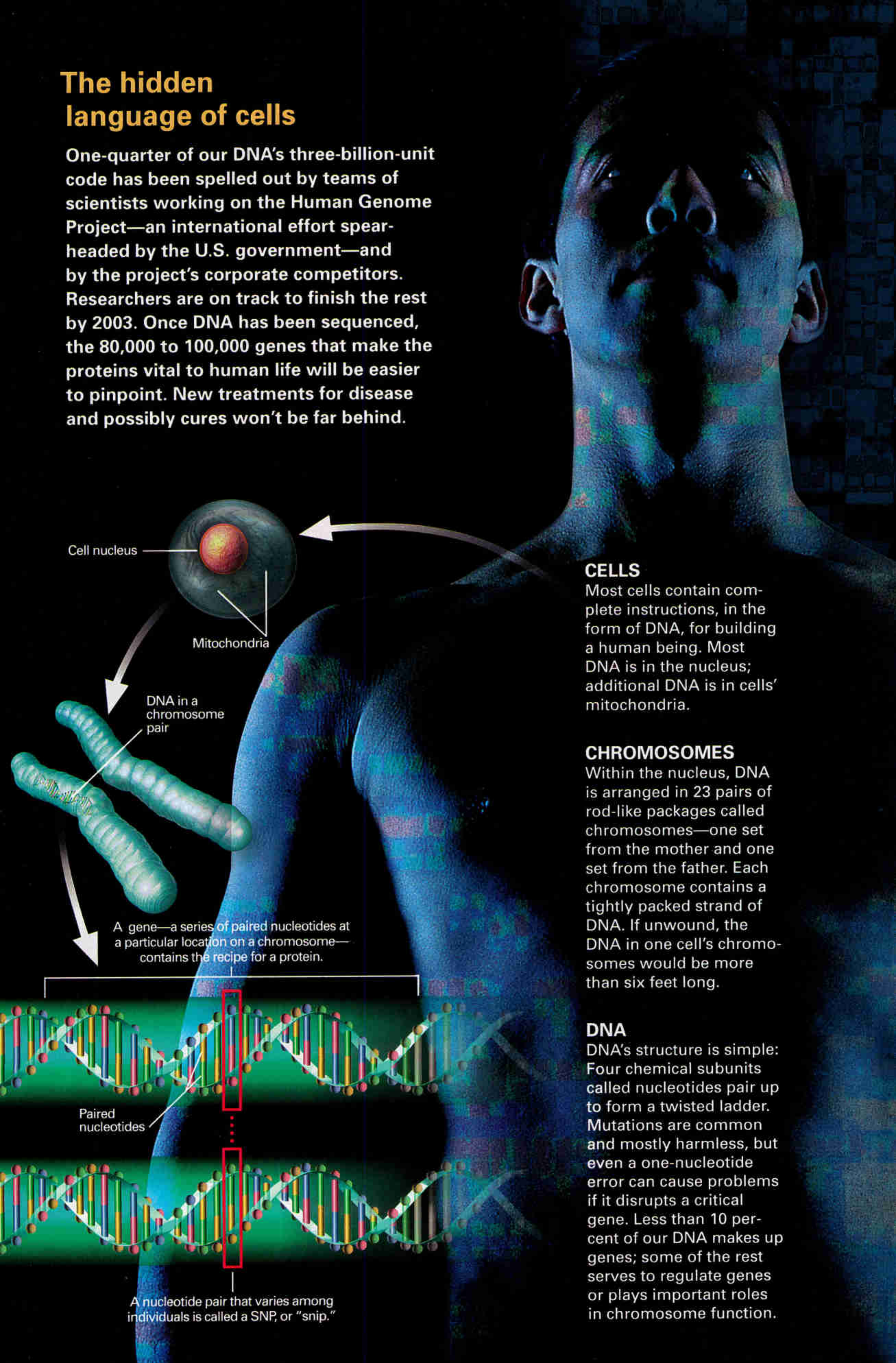
Never mind how a twentysomething bartender knows what people were drinking 50 years ago—I now know how to pay my respects. I order a pint of Abbot and carry it over to a chair by the fire.

The secret that Watson and Crick (or Crick and Watson, as they are referred to on the Eagle's side of the Atlantic) had uncovered was the shape of a now familiar molecule called deoxyribonucleic acid. A Swiss scientist had isolated the chemical from the white blood cells of pus way back in 1869, but neither he nor anyone for over half a century had any idea of its importance to life. It wasn't until a few years before Watson and Crick began work that an American bacteriologist named Oswald Avery demonstrated that DNA was the stuff of genes—discrete, inheritable packets of information aligned along the chromosomes inside the cell's nucleus.

Watson and Crick puzzled out that DNA is shaped like a twisted staircase—the famous double helix. The two strands of the helix consist of immensely long strings of subunits called nucleotides. These, in turn, contain sub-subunits called bases that are referred to by the letters A, T, G, and C. (They stand for adenine, thymine, guanine, and cytosine.) Think of those four bases as letters in a four-letter alphabet. Just as we arrange the letters of our alphabet into meaningful words, the A's, T's, G's, and C's that make up our genes are arranged into three-letter "words" comprehensible to the machinery of the cell. Each gene is a sentence composed of a precise order of these words, telling the cell to manufacture a particular protein, be it an enzyme that helps you digest your lunch, an antibody marshaled to fight off an otherwise lethal infection, or one of the *(Continued on page 54)*

The hidden language of cells

One-quarter of our DNA's three-billion-unit code has been spelled out by teams of scientists working on the Human Genome Project—an international effort spearheaded by the U.S. government—and by the project's corporate competitors. Researchers are on track to finish the rest by 2003. Once DNA has been sequenced, the 80,000 to 100,000 genes that make the proteins vital to human life will be easier to pinpoint. New treatments for disease and possibly cures won't be far behind.



CELLS
Most cells contain complete instructions, in the form of DNA, for building a human being. Most DNA is in the nucleus; additional DNA is in cells' mitochondria.

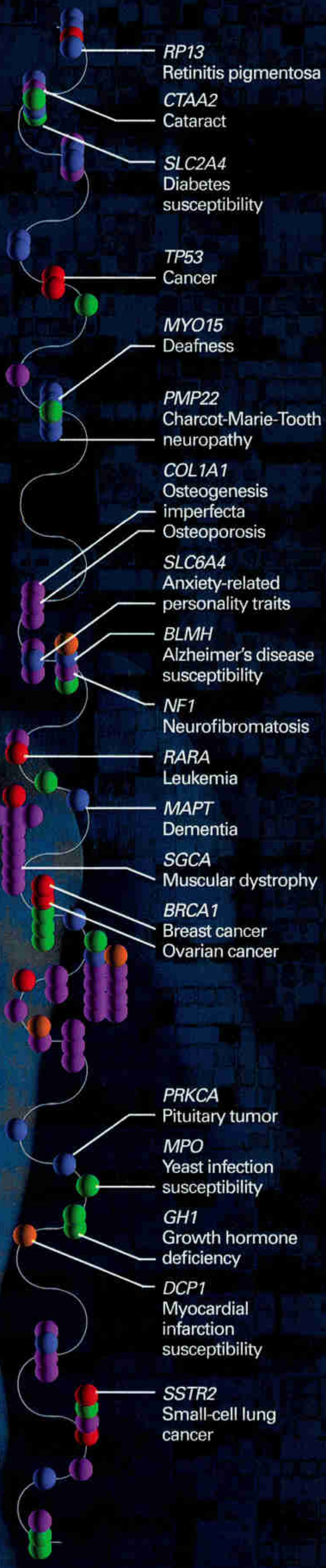
CHROMOSOMES
Within the nucleus, DNA is arranged in 23 pairs of rod-like packages called chromosomes—one set from the mother and one set from the father. Each chromosome contains a tightly packed strand of DNA. If unwound, the DNA in one cell's chromosomes would be more than six feet long.

DNA
DNA's structure is simple: Four chemical subunits called nucleotides pair up to form a twisted ladder. Mutations are common and mostly harmless, but even a one-nucleotide error can cause problems if it disrupts a critical gene. Less than 10 percent of our DNA makes up genes; some of the rest serves to regulate genes or plays important roles in chromosome function.

The stories in our genes

Cancers
Cardiovascular disorders
Other
Metabolic/endocrine disorders
Neurologic/psychiatric disorders

Someday DNA tests may provide instant snapshots of future ailments and life expectancy, but not yet. Genes for more than 1,200 disorders have been identified (selected examples below and left), but most people probably can learn more from their parents' health history than they can from a DNA printout (background). Most of us carry a few defective genes with no signs of disease, and many genes only contribute to susceptibility. Lifestyle choices such as diet and smoking and environmental factors can raise or lower disease risk.



CHROMOSOME 1
- Malignant melanoma
- Prostate cancer
- Deafness

CHROMOSOME 2
- Congenital hypothyroidism
- Colorectal cancer

CHROMOSOME 3
- Susceptibility to HIV infection
- Small-cell lung cancer
- Dementia

CHROMOSOME 4
- Huntington's disease
- Polycystic kidney disease

CHROMOSOME 5
- Spinal muscular atrophy
- Endometrial carcinoma

CHROMOSOME 6
- Hemochromatosis
- Dyslexia
- Schizophrenia
- Myoclonus epilepsy
- Estrogen resistance

CHROMOSOME 7
- Growth hormone deficient dwarfism
- Pregnancy-induced hypertension
- Cystic fibrosis
- Severe obesity

CHROMOSOME 8
- Hemolytic anemia
- Burkitt's lymphoma

CHROMOSOME 9
- Dilated cardiomyopathy
- Fructose intolerance

CHROMOSOME 10
- Congenital cataracts
- Late onset cockayne syndrome

CHROMOSOME 11
- Sickle-cell anemia
- Albinism

CHROMOSOME 12
- Inflammatory bowel disease
- Rickets

CHROMOSOME 13
- Breast cancer, early onset
- Retinoblastoma
- Pancreatic cancer

CHROMOSOME 14
- Leukemia / T-cell lymphoma
- Goiter

CHROMOSOME 15
- Marfan's syndrome
- Juvenile epilepsy

CHROMOSOME 16
- Polycystic kidney disease
- Familial gastric cancer
- Tuberous sclerosis-2

CHROMOSOME 17 (shown at left)

CHROMOSOME 18
- Diabetes mellitus
- Familial carpal tunnel syndrome

CHROMOSOME 19
- Myotonic dystrophy
- Malignant hyperthermia

CHROMOSOME 20
- Isolated growth hormone deficiency
- Fatal familial insomnia
- Creutzfeldt-Jakob's disease

CHROMOSOME 21
- Autoimmune polyglandular disease
- Amyotrophic lateral sclerosis

CHROMOSOME 22
- Ewing's sarcoma
- Giant-cell fibroblastoma

X CHROMOSOME
- Colorblindness
- Mental retardation
- Gout
- Hemophilia
- Male pseudohermaphroditism

Y CHROMOSOME
- Gonadal dysgenesis

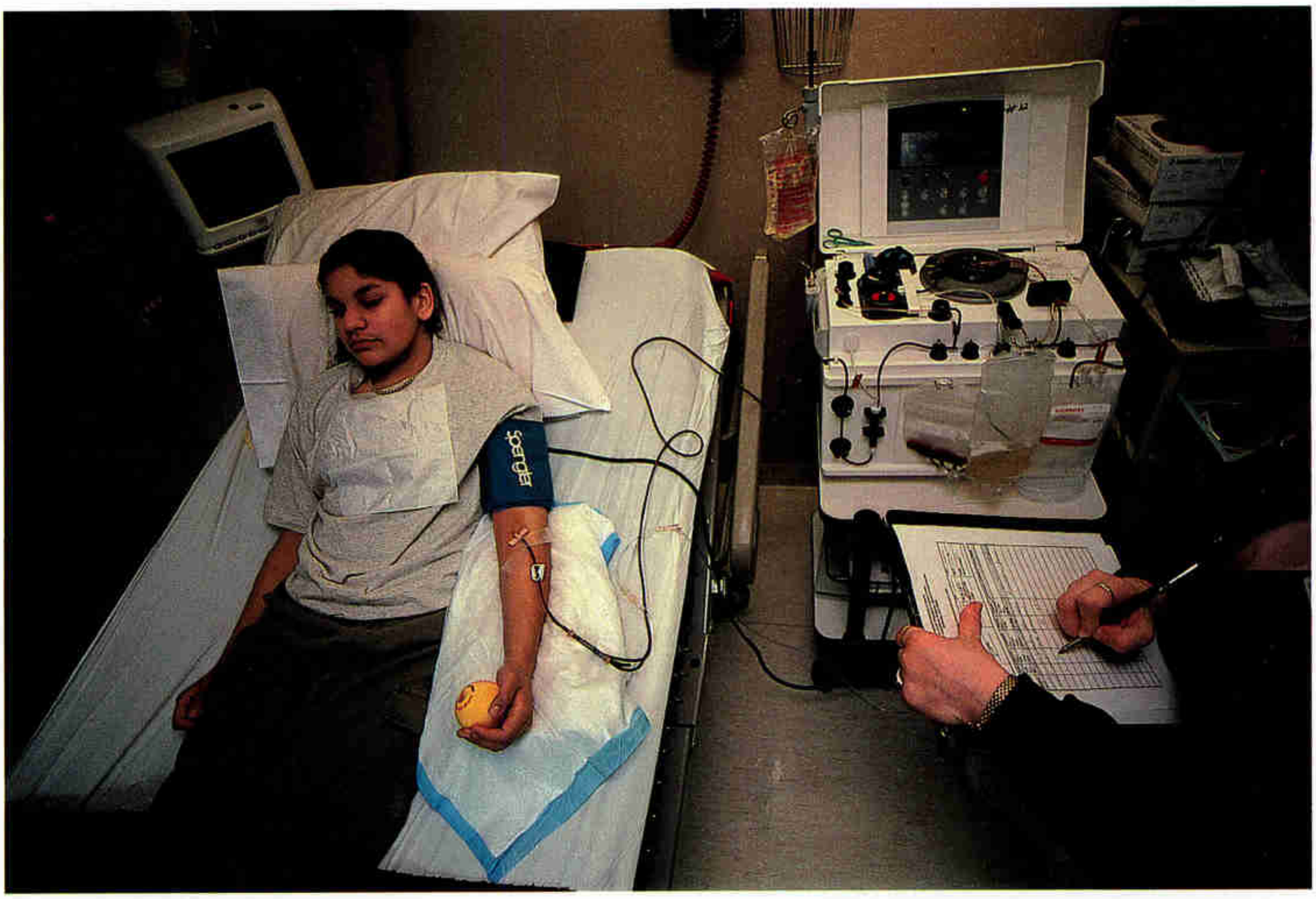
MITOCHONDRIAL DNA
- Leber's hereditary optic neuropathy
- Diabetes and deafness
- Myopathy and cardiomyopathy
- Dystonia

SOURCE: VICTOR A. McKUSICK, JOANNA AMBERGER, AND ADA HAMOSH, ONLINE MENDELIAN INHERITANCE IN MAN *(WWW.NCBI.NLM.NIH.GOV/OMIM/)* AND GREG SCHULER, NATIONAL CENTER FOR BIOTECHNOLOGY INFORMATION; ART BY CHRISTOPHER SLOAN, NGS STAFF, AND DOUG STERN; PHOTOGRAPH BY O. LOUIS MAZZATENTA

Living With Alzheimer's Disease

The first symptoms of Alzheimer's disease hit Ina Savage, 58, about a decade ago. The woman who organized her Baltimore family's life began to forget what to buy at the grocery store and what to pack for vacations. Then in 1996 the diagnosis came: early-onset Alzheimer's, a form that strikes before age 65 and accounts for about 15 percent of cases. Ina is still feisty and talkative, but she's not the person her husband and children remember. Her daughters guide her to and through the supermarket. Dressing is a challenge. Recipes slip from her mind.

Eight genes have been linked to Alzheimer's, but there's no cure yet, and conclusive genetic tests won't be available for several years. Would Ina's daughters take such a test? "It would be irresponsible not to; I want to start a family," says Serena (with newspaper). Pauline (red hair) disagrees: "If I get Alzheimer's, I get it." Lina is cautious. "What if an insurer learned the test was positive and decided not to pay for treatment?"



PIONEER Ashanthi De Silva was, at age four, the first human to receive gene therapy, a procedure that inserts new DNA to do the work of defective genes. Now 13, she still gets follow-up care for her rare immune disorder (above), but she is able to attend school (opposite), where classmates treat her like anybody else. Scientists and reporters are more bothersome, she admits. "But if it helps people learn, it's good."

receptor proteins in your brain that enables you to read and understand this paragraph.

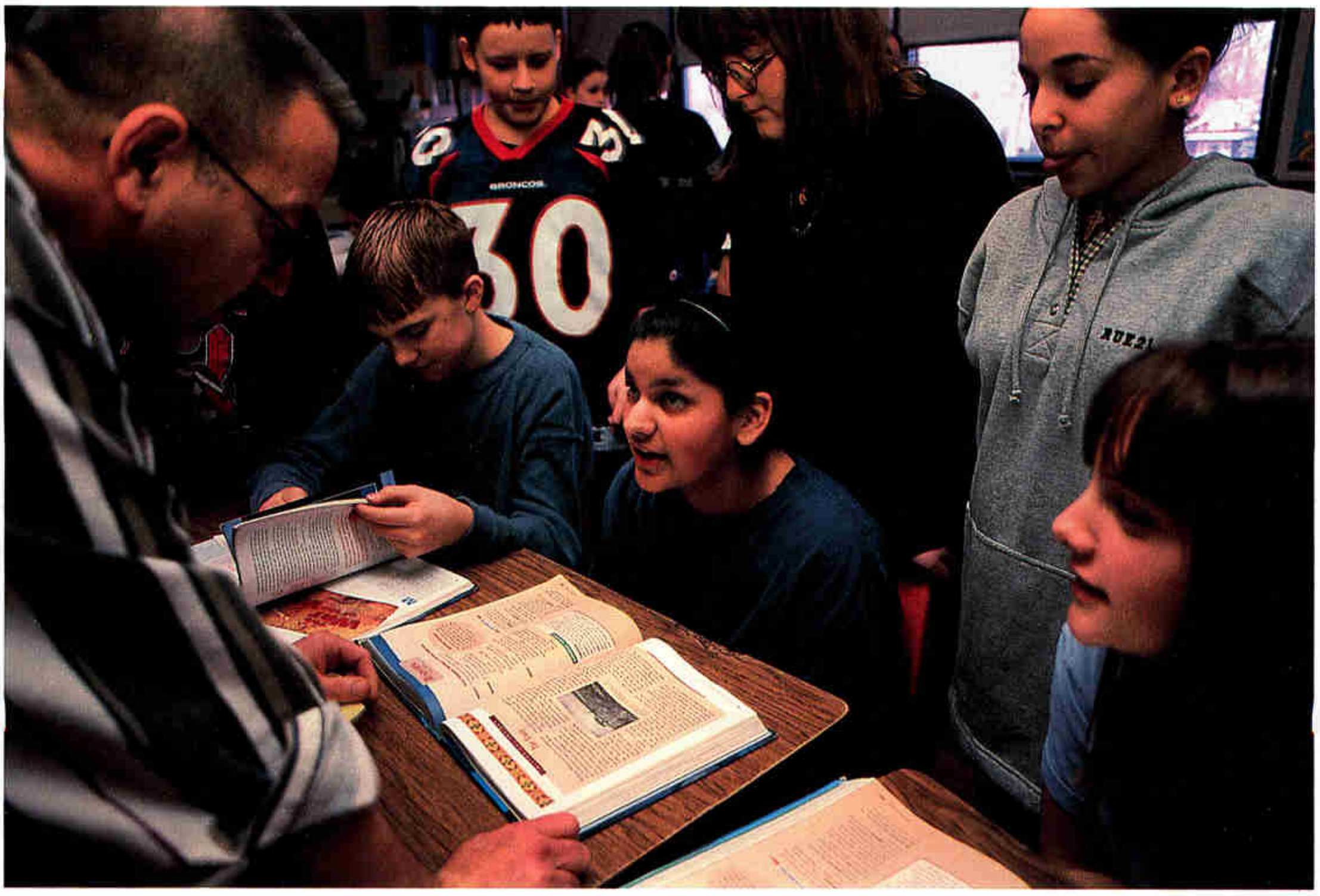
That simple formula—one gene makes one protein—is part of the central dogma of molecular biology. Like any dogma, it skips over a great deal of detail. In order to make a protein, a gene actually needs help from all kinds of other proteins, such as hormones and enzymes. It needs to know when to turn itself on and when to turn off.

The genes of higher organisms are especially complex, their chemical messages riddled with meaningless strings of letters that have to be spliced out before the genes can do their work. Byzantine patterns of repeated words and lengthy sprawls of seemingly nonsensical sequences mask essential instructions not yet understood. None of this was known, of course, back when Watson and Crick were celebrating in the Eagle pub.

"The great and wonderful thing about DNA back then was that it seemed so simple," says Jim Watson today in his office at Cold Spring Harbor Laboratory on Long Island. "Initially everyone *liked* DNA. It's not that we dislike it now, but it's frightening trying to figure out what you do with all that complexity. My brain can't handle it."

IF YOU ARE LOST, it helps to have a map. I drive south out of Cambridge to keep an appointment at the Sanger Centre, an elegant thrust of concrete and brushed metal rising from the grounds of an old estate. The Sanger Centre is one of the most productive contributors to the international Human Genome Project, a multibillion-dollar effort to map all the estimated 100,000 genes on our 23 pairs of chromosomes and read their entire sequence, letter by letter. It is a colossal task, for there are billions of letters.

"All the information required to make a human being is written into our DNA," says John Sulston, the Sanger Centre's affable, bushy-bearded director. "We can even put an upper limit on the size of it—about a gigabyte



of data. Your entire genome will easily fit on the hard disk in your desktop PC."

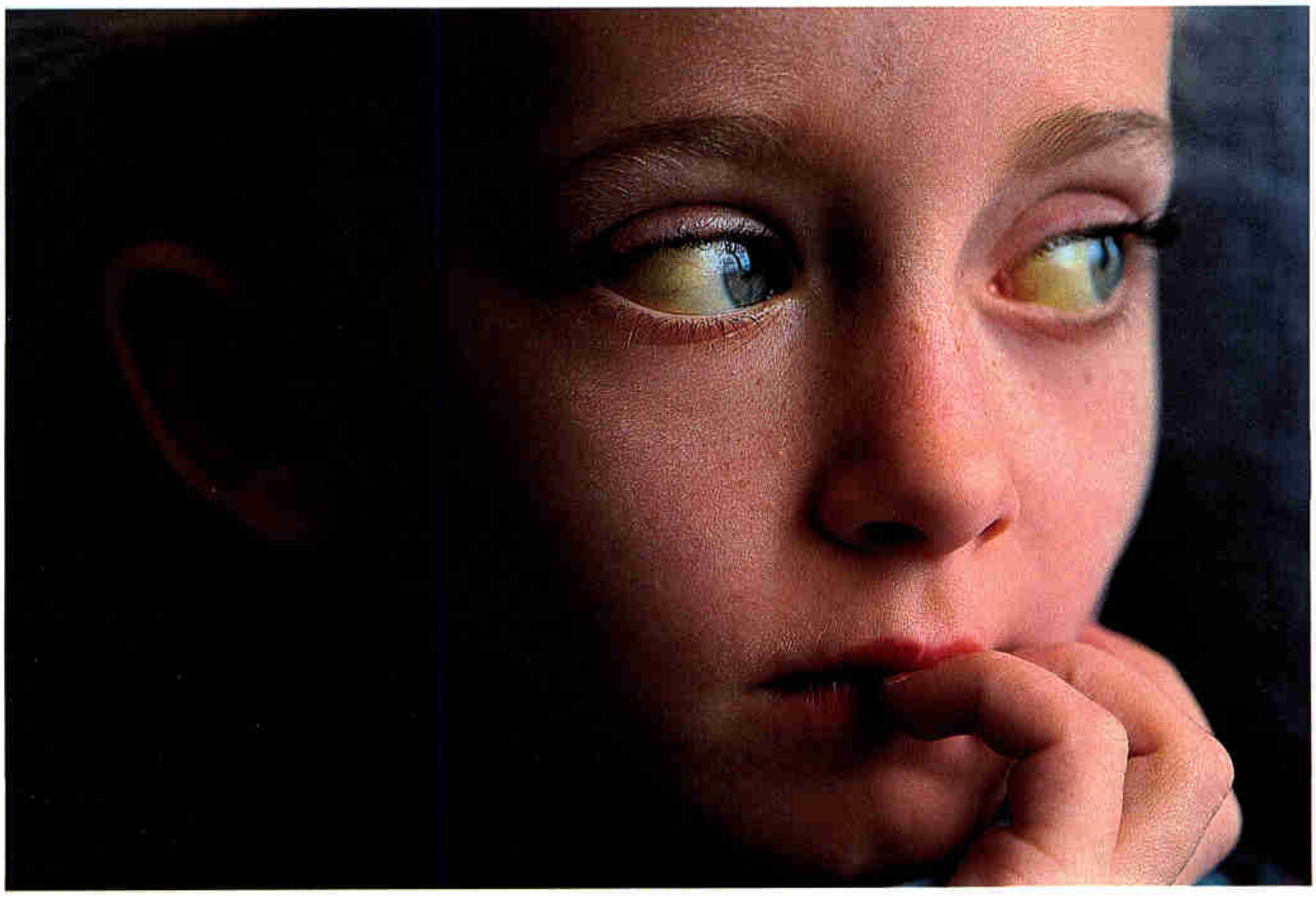
Understanding human biology as a quantity of data requires a strange, steely new kind of science. The Sanger Centre is not a laboratory in the traditional sense. It is a factory. In back rooms gleaming machines whir through regimented tasks. The needle-tipped arm of a robot sampler plunges down to sip a tiny portion of DNA from a grid of samples, then swings headlong to the other end of its range of motion and spits the solution into another receptacle. Across the hall I am shown the heart of the facility: 80 automated sequencing machines running at full capacity 24 hours a day, seven days a week. Another 50 are humming away in other rooms. Hundreds more are pouring out human code at other genome centers in the United States.

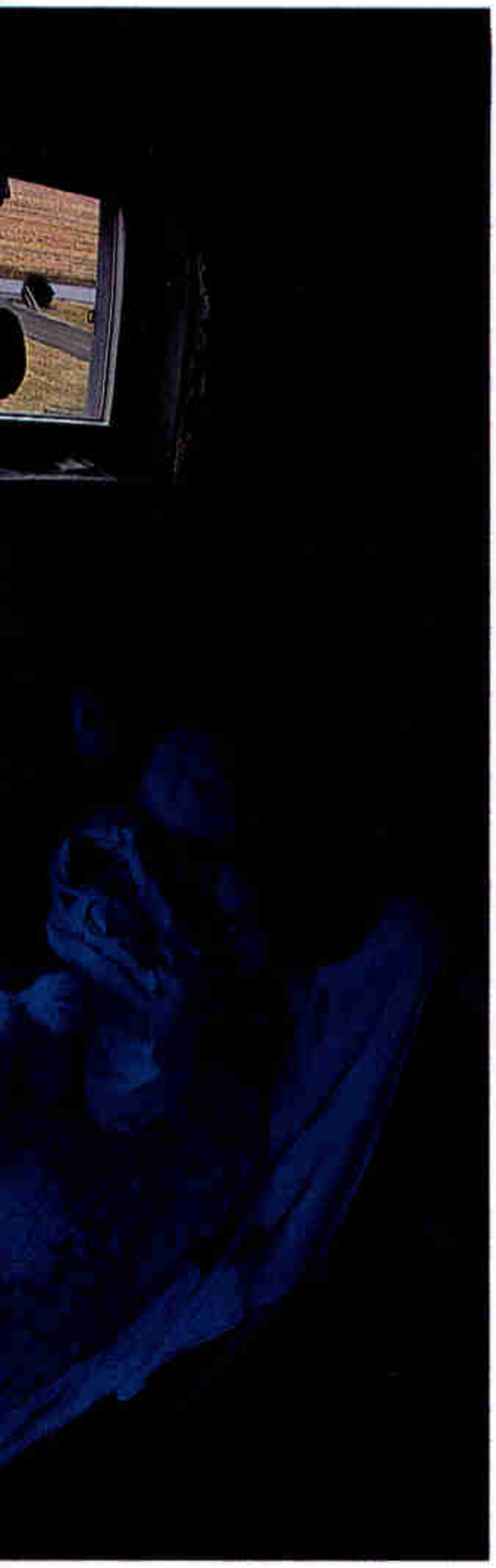
"This is the most important organized scientific effort that humankind has ever attempted," says Francis Collins, director of the Human Genome Project at the National Institutes of Health outside Washington, D.C. "It dwarfs going to the moon."

"People have trouble understanding the sheer magnitude of this work," says Craig Venter, head of Celera Genomics in Rockville, Maryland, a private company challenging the government effort for the right to claim discovery of the code of human life. According to his estimate, "There are roughly three and a half billion letters in the human genome. If it were a book and you could read ten letters of it every second, it would take 11 years to recite the whole text."

Even if we had 11 years to spare, a simple recitation of the code would give no hint of the way it makes a human life. Instead of thinking of the genome as a book, imagine it as a piano keyboard. Each piano key represents one gene. If you press down on a key, you hear a single note. That note corresponds to the protein that the gene specifies. If you press the key again, you will hear the same note, and again, monotonously, every time the key is played.

But if you have lots of keys, you can make music. Just so, our various cell types play upon the immense keyboard of the genome: They combine notes, playing some genes together as chords, tripping several together in a phrase, gathering bundles of notes to create the complex and wonderful effects that find expression in our biological being. Just as a pianist doesn't play all the keys in every piece, only some of the genes get played in the cells of each organ. Sonata in the Key of Kidney.





BLUE LIGHT helps rid a Mennonite girl of toxic levels of bilirubin, a blood product that her liver cannot break down, making her eyes yellow. The culprit: Crigler-Najjar syndrome, a one-nucleotide error in a recently identified gene. Half the cases in the United States occur among Pennsylvania's Amish and Mennonites, who may have inherited the mutation from one founding family 16 generations ago. Soon this girl may begin a new gene-therapy trial.

The Brain Fantasia. Variations on the Theme of Gonad. Beautiful music, all of it. But think what can happen to a piano concerto if an important key sticks or sounds the wrong note when struck. Such a flaw will ruin every passage where that key is played.

In some cases it will destroy the music entirely. In the United States one child out of every 3,900 is born with cystic fibrosis, the most common deadly hereditary disease among Caucasians. The mucus in the lungs is abnormally thick, leaving the child vulnerable to repeated infections that erode the lungs' tissues and eventually the ability to breathe. Half of all sufferers die before their 31st birthday.

Ten years ago researchers in Toronto and at the University of Michigan traced the cause of the disease to a defective gene on chromosome 7. Such single-gene defects account for 3,000 to 4,000 other inherited diseases. Sickle-cell anemia is caused by nothing more than a substitution of a T for an A in the spelling of a gene governing the manufacture of the hemoglobin protein in red blood cells. Huntington's disease, the lethal degenerative condition of the brain that killed folk singer Woody Guthrie, occurs because a gene near the top of chromosome 4 contains a series of up to 85 extra "stutters" on the letters CAG, playing like a scratched record on a turntable.

It took more than a decade for scientists to track Huntington's disease to a specific gene—and it was an easy target. Most diseases, including the common killers like cancer and heart disease, stem from disruptions in the interaction among several genes and between genes and the environment. When you hear about the discovery of the gene for breast cancer, Alzheimer's disease, or some other ailment, what is usually meant is that someone has found a gene implicated in some forms of the disease, in some people, some of the time. Rooting out the genetic component in most illnesses is still a dauntingly difficult task. Luckily it can be a little less daunting in some parts of the world than in others.

A FEW DAYS after visiting Cambridge I am in Iceland's West Fjords riding along the edge of the world in a red Toyota Land Cruiser. Falling snow has begun to slicken the road, and I am trying not to look down, where a hundred feet below an angry dark tongue of the Arctic Ocean licks at a black beach. At the wheel is a soft-spoken, fast-driving orthopedist named Thorvaldur Ingvarsson. We are on our way to see some of his patients who are afflicted with osteoarthritis, a painful, crippling disease of the joints. In his wool sweater and glasses Thorvaldur could be just a quiet country doctor making his rounds in a remote corner of an isolated country. But he isn't interested in merely treating people with osteoarthritis. He wants to find its cause. With help from a formidable ally—the entire population of Iceland, living and dead—he is getting close.

"This disease is five times as common in Iceland as in most other countries," he tells me. "People think it is because of the hard work here, the fishing and the farming. My theory is it is not the job. It is the genes."

In 1987 a woman who had already had one

BORN OLD: Dolly, the first mammal cloned from an adult cell, bleats at Scotland's Roslin Institute. Dolly was a milestone in efforts to turn farm animals into living drug factories. Some sheep have been genetically altered to produce a protein in their milk that is being tested in Northern Ireland to help cystic fibrosis patients breathe easier (opposite). As for Dolly, her cells may have aged as much as her "parent."

hip replacement and would soon need another came to Thorvaldur. She mentioned that ten of her sixteen siblings also had the disease.

"It was unbelievable," he remembers. "I looked up all the people who had received hip replacements in Iceland. In the one extended family this woman belonged to, there were records for 700 cases of osteoarthritis of the hip stretching back five generations."

Using family histories to tap the roots of human disease is standard practice in genetics. If you can ferret out the difference in DNA between sick people and their healthy relatives through several generations, you will have a big leg up on knowing what is making them sick. Unfortunately there is rarely a single genetic flaw behind every case of an inherited disease because such flaws arose in the distant past in different places. In most populations, genes have been shuffled and reshuffled through generations of migrations and interbreeding, making the search for a link among the diseased a murky business.

Look into the Icelandic gene pool, however, and you can see right to the bottom. The country was originally populated in the ninth century by just a few hundred Norwegian Vikings and a handful of Celts. Since that time few immigrants have been tempted to its desolate shores. A series of calamities through the centuries—plague, smallpox, and volcanic eruptions leading to massive famine—further reduced the genetic muddle.

To make matters even better for geneticists, Icelanders have always had a passion for genealogy; almost everyone knows the names and birthplaces of their ancestors four or five generations back, and meticulous written records extend all the way back to the original settlers. Most genetic diseases in Iceland can thus be traced to mutated genes in one or two individuals in the past few hundred years, making the search for errant genes much easier than in other countries.

"Every one of us is walking around with replicas of the genomes inherited from the

settlers," says Kári Stefánsson, head of DeCode Genetics in Reykjavík, which is exploiting Iceland's genetic simplicity to hunt for disease genes. "This is reincarnation in a literal sense."

With help from Thorvaldur, DeCode geneticist Stefán Einar Stefánsson has tracked down the chromosomal location of the gene responsible for most of the hip replacements in Iceland. (The defective gene was brought to Iceland in the middle of the ninth century by one of the original immigrants.) Soon Thorvaldur and Stefán hope to capture the code of the gene itself.

That information could be used to develop diagnostic tests for osteoarthritis not only here but also abroad. Icelanders have been isolated for a thousand years, but their genes derive from the same ancestral pool as other Europeans—and back in time to other populations as well. In the long run knowing the gene's code could provide the missing key needed to design a drug that attacks the disease at its source, ending the need for joint replacement in thousands of patients all over the world.

Near the tiny fishing village of Tálknafjördur, Thorvaldur and I stop at the farmhouse of Ragnheidur Magnúsdóttir, who has already had both her hips and knees replaced. Before she became ill, she welcomed the hard work needed to help her husband run the farm. Now all she can manage is to cook for the farmworkers, clutching the stove for support.

"You can't behave like you did before," she says. "I want to do everything I can to help find a solution to a disease like this."

Ragnheidur has already done something: She has given her blood to DeCode. Last year, after fractious debate both here in Iceland and among scientists abroad, Iceland's Parliament passed a law giving a company, expected to be DeCode, exclusive rights to create and maintain a gargantuan database containing the country's health records. Eventually this database will be combined with Icelandic genealogical records and DNA profiles. Integrating this information into a single database will make it much easier to link diseases and propensities for disease to particular genetic patterns. Most Icelanders supported the bill.

But in the minds of DeCode's critics the database is an ominous development. What does it mean when a single private company is licensed to sell the genetic legacy of an entire population? The identities of the individuals in the database are supposedly protected by elaborate encryption, but what happens if there are leaks? *(Continued on page 64)*

Cystic Fibrosis: A Hidden Killer

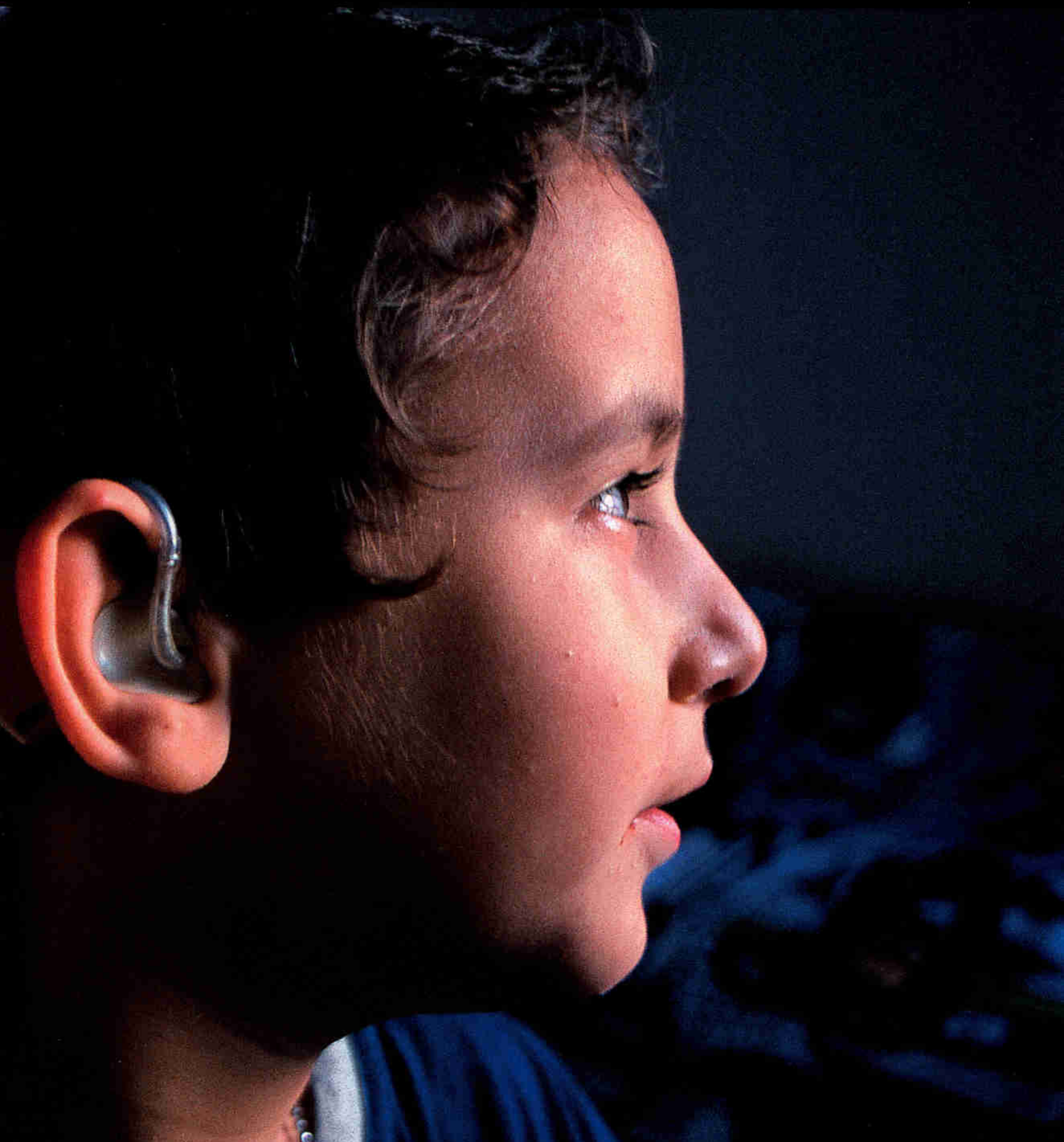
Three of Kathy and Jack McGowan's five children have cystic fibrosis (CF), the most common deadly genetic disease in the U.S. Its cause is a defect in a gene that controls the balance of salt in lung cells. Mucus builds up, fostering infections that can be lethal. At present, one of every two CF sufferers dies before age 31.

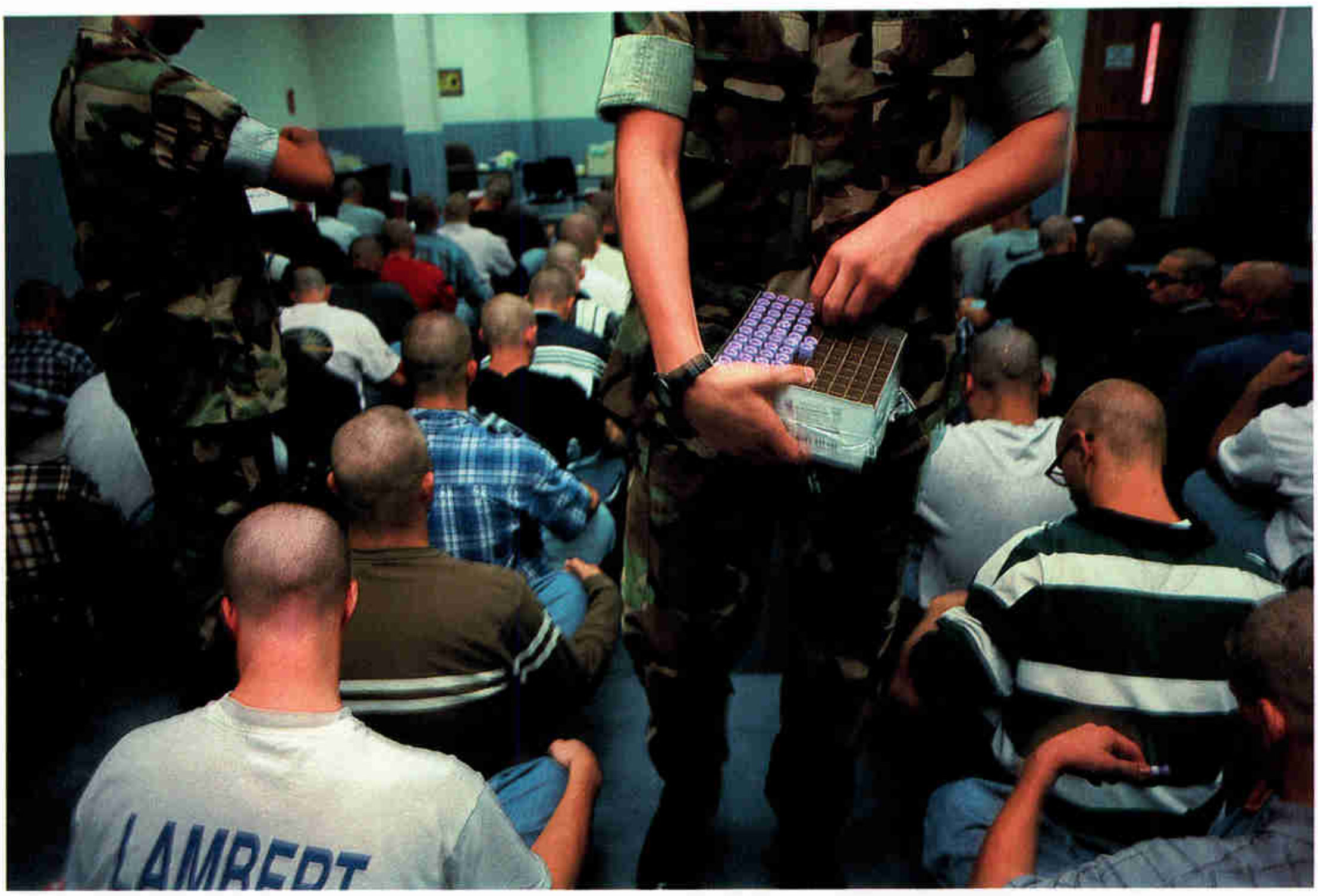
While John (right, at far right) waits for a lung capacity test (below right), Kathy makes an entry in a notebook that records details of treatment. At home (below) the McGowans pound Matt's and John's backs to loosen mucus in their lungs.

To develop CF, a child must inherit the defect from each parent. One in 31 Americans is a carrier; with each pregnancy a carrier couple has a 25 percent chance of having a child with CF. After John was diagnosed, the McGowans kept having children, trusting in faith. Today, options have increased, including *ex utero* testing of eggs.

WITHOUT HEARING AIDS, Chai Cohen, right, and his sister Hila of Netanya, Israel, can't hear their parents. "There may be more than a hundred genes linked to deafness," says geneticist Karen Avraham of Tel Aviv University, "but only 15 have been isolated so far."

A defect in just one gene can cause hearing loss. Avraham and Palestinian researcher Moien Kanaan of Bethlehem University hope to find the genetic causes of deafness in their region, where in some places hearing impairment affects as many as one in ten.





MARINE RECRUITS give up more than hair at boot camp on Parris Island, South Carolina. Blood samples are collected and sent to a warehouse in Maryland (opposite) to be stored in freezers until DNA is needed to identify combat or accident victims whose remains are too mutilated for conventional analysis. DNA from the armed forces' archive of 2.75 million specimens has been used to identify 192 bodies.

Can an Icelander face the loss of a job because someone finds out he has a gene predisposing him to alcoholism or schizophrenia? Furthermore, DeCode plans to market its information to anyone who can pay the price, including foreign pharmaceutical firms and health insurance companies. What happens if my health insurance company or yours discovers that we carry a gene that in Iceland causes osteoarthritis or diabetes?

"What worries me about this research," says Thorvaldur, "is what to do with the results."

I DON'T HAVE TO WORRY about the results of my GeneChip test at Affymetrix because its fate has been decided in advance. Two days after the DNA is extracted, Kyle O'Connor and I are sitting before a computer terminal displaying a grid of bright orange, green, and blue squares. Standing beside us is Anne Bowdidge, the public relations director who has been patiently showing me around—and is also making sure I don't see too much. The colored grid represents 1,500 places along my chromosomes where variations of a single letter in the genetic code occur. I click the mouse button randomly on an orange spot on the grid and up pops a window telling me that at this particular address on my genome I have a G where other people might have a C.

"I'm not sure you're supposed to know that," says Anne. "We don't want any of this coming back to haunt you."

Neither do I. In most cases such variations, called SNPs, or "snips" (shorthand for "single nucleotide polymorphisms"), don't make any difference in the functioning of the individual. They are highly useful, however, as markers, like landmarks on a map, for any genes that may be discovered near them that do matter. I have been told that no diseases are known to be associated with having one snip or another at any of these 1,500 spots. But there may be, just as soon as researchers start using the chip to look for them. Because snip chips can scan

such a great swath of genetic terrain, they may eventually be able to untangle the roots of diseases involving more than one gene. At that point the results of my test *could* start to matter, possibly a great deal.

For that reason Affymetrix and I have agreed that the data will be destroyed after I finish viewing it on the screen. But let's suppose the information were to survive. Who should have access to what it might say about my genetic condition? Affymetrix? My HMO? Me? How would knowing such information affect the way I conduct my life?

"It all depends on how powerful the information is," says Hank Greely, a law professor specializing in genetics at Stanford University, just up Highway 101 from Affymetrix. "Look at Huntington's disease. It is invariably fatal after a horrible decline. If you tell somebody they've got that variation of the gene, you've given them a hell of a lot of information."

Such knowledge may be too much to bear. A diagnostic test for Huntington's disease has been available for years now, but most people at risk decline to take it. Legislation might protect them against genetic discrimination in health insurance and employment, but what about the psychological costs of knowing too much about one's genetic endowment?

"The real implications of genetic testing are familial," says Greely. "Is your wife going to divorce you when she finds out you have the Huntington's disease variation? How will the parent feel who gave it to you? How do you tell your kids you may have given it to them?"

Greely is quick to point out, however, that a rare disease like Huntington's, where a bad gene determines an inescapable fate, is not the right model for understanding the impact of most genetic information. In the overwhelming number of cases, genes only predict susceptibility to diseases, not certainty. That kind of information, Greely explains, isn't of great interest to health insurance companies or employers because they already have better ways to predict who is likely to get sick and who isn't. The number of times I saw my doctor last year provides a far more powerful forecast of how much I'll cost my HMO this year than most anything my snip chip would reveal.

On the other side of the balance is all the new knowledge of the genome that can be put to good use. If you carry one of six genes known to be involved in colon cancer, for example, you have up to a 100 percent chance of developing the disease—if you don't know you are at risk. If, on the other hand, you discover through a simple blood test that you are

Genetic Justice Comes to Guatemala

Long after a life's violent end, geneticists like Michele Harvey-Blankenship (right, with hoe) of the University of Washington can use DNA to tell a victim's story and bring criminals to justice. More than 200,000 Guatemalans disappeared or were killed in decades of civil war. Michele was called in to corroborate eyewitness reports of political executions in the 1980s.

Trenches are dug near suspected mass graves. If remains are found, the team seeks the body's most durable DNA repositories—teeth and bone. An undamaged tooth's interior can retain testable DNA for thousands of years. Mitochondrial DNA, inherited from mothers, is compared with DNA from surviving maternal relatives. Michele has identified bodies in five mass graves in Guatemala, findings that will help rewrite history. "No one can argue that these killings didn't happen," she says. To a Maya family (below right), recovering remains of loved ones has an even greater meaning: Until properly buried, they believe, their dead are in a state of unrest.

a carrier, you can elect to have regular check-ups and remove any polyps that develop in your colon before they become malignant. In that case your chance of getting the disease falls close to zero. So now your genes aren't deciding whether you live or not. You are.

"Genes are not fate," says Greely. "Usually. For most of us."

With all the emphasis on genes that cause disease, it is easy to forget that the genome is the recipe for life, not death. Behind the colored array of my snip chip may lie information on how I metabolize the contents of a tuna sandwich, why my eyes are blue or my hairline is not where it used to be, or why I'd rather ski than play golf.

We know genes play a role in influencing behavior and personality; studies showing that identical twins raised apart share an uncanny number of behavioral traits back that up. But so far attempts to tag a particular behavior to a particular gene have been problematic because such complex behaviors necessarily involve the cooperation of many genes. On the genomic piano, behaviors and personality traits are not single notes but intricate compositions.

I linger a little while longer over the image on the screen, but the exercise has run its course. It is unlikely that the information on this chip, even if I knew its meaning, would say anything about why I am absentminded, sleep poorly, or chose to be a writer. But these 1,500 snips offer a hazy glimpse into the genome. More snips are being discovered every day. Within a year a rough draft of the complete genetic code of a typical human being will be posted on the Internet by Celera Genomics, the Human Genome Project, or both for anyone to explore. Celera's Craig Venter envisions a time soon when family doctors and even individuals can log on to a website and test specifics of their own genome against a vast database of knowledge about disease, behavior, diet, and drugs. What hypertension drug targets my genetic profile of the disease? What kind of fats do I have trouble metabolizing so I can know to avoid them?

"Imagine a day when these technologies are more advanced and more available," says Affymetrix's Steve Fodor. "People can begin to look for themselves at how their genetics are likely to affect everything from their eating habits to the kind of perfume they choose to wear. We think genetic information will give people more control of their lives, not less."

As arranged with the Affymetrix lawyers, when I finish with the image of my genome, I drag the data file to the trash bucket on the screen and delete it. I had anticipated a sense of relief when this testimony to my genetic identity was safely silenced. What I hadn't counted on was a twinge of regret.

COMPANIES LIKE Affymetrix and Celera are prospecting the genetic code for glimpses of the future. Far away, on a hillside in the tiny, forlorn Guatemalan village of Tzanimacabaj, a young geneticist named Michele Harvey-Blankenship is using DNA to dig up the past. On my right, dressed in blue jeans and a white T-shirt, Michele shovels dirt into a wheelbarrow and dumps it over the edge of a wooded slope. On my left a villager named Juan Calel Mateo tears into the ground with a broad-bladed hoe. Somewhere beneath its cutting edge lie the bones of his father.

Like thousands of other Maya Indians, Mateo's father was killed during the long Guatemalan civil war, his body heaved into a hole in the ground with half a dozen other innocents from this village. In the Maya belief system those who are buried without proper ceremony are not truly dead. They have no peace. They have no identity.

That is why Michele Harvey-Blankenship is here. Based at the University of Washington in Seattle, Michele specializes in using DNA to identify victims of genocide and other human rights violations. Working with the Foundation for Forensic Anthropology of Guatemala, one of only a few organizations in the world performing this arcane and grisly task, Michele reunites the remains of the disappeared with their living relatives. She has worked in Bosnia, Argentina, El Salvador, and several times here in Guatemala. The work is not just for the comfort of families and the souls of the disappeared. The ability to bring the perpetrators of genocide to justice often depends on having an identified victim.

"We try to reconstruct a skeletal biography of the person through traditional forensics," says Fredy Peccerelli, the foundation's indefatigable young director. "But the most we can

ANCIENT JEWISH RITUAL, the redemption of the firstborn son requires payment to a Cohen, far left, a member of a priestly clan that traces its paternal lineage back to Aaron, the first priest. Researchers have found genetic markers on the Y chromosome that may have been passed from father to son for more than 100 generations.

do is get a tentative identification. With DNA that changes to a positive identification."

Trailing behind every one of us as we move through our days is an invisible wake of identity. Sometimes, someone's wake catches up to him. Think of the bloody glove or the stained Gap dress. In the last decade DNA fingerprinting has become an indispensable tool in investigations of murder, rape, and other crimes where the offender might leave at the scene a litter of personal bar codes in the form of hair, skin, and body fluids.

Last year the FBI opened a national DNA database of people convicted of certain serious offenses. England already has a DNA database of everyone convicted of a crime since 1995, as well as of suspects in unsolved cases. Because of these databases the guilty will be convicted more often and, more important, the innocent will be exonerated.

The more powerfully DNA can link a person to his past, the more people will worry about how that power will be abused. Last December the mayor of New York said he'd have "no problem" if all newborns in the city were to have their DNA fingerprinted. Does his city government, or mine, have a right to a record of my genetic identity? Will this wonderful tool for solving crime make suspects of us all?

Such ethical dilemmas are real, but they belong to a world far from this mangled hillside. The only people who need to fear DNA tests on these bodies are the ones who put them here in the first place. The chief suspect, a former paramilitary patrolman in the village, is in hiding close by. He has done everything possible to impede the excavation, including threatening the villagers.

If all goes well, we will find the skeletons, and Michele will take samples of bone and teeth back to Seattle. She will then extract a certain kind of DNA called mitochondrial DNA, which is plentiful even in badly decayed bone. She will also take back blood samples from the deceased's presumed kin and from unrelated members of the community as well. If DNA can be obtained from the victim and his relatives, it will show identical sequences

PRAYER SHAWLS cloak Cohanim blessing suppliants at Jerusalem's Western Wall, an inherited duty that is theirs alone. Would-be Cohanim have contacted the discoverers of the clan's genetic bond in hopes of proving that they belong—as have some members,

perhaps hoping to shed certain restrictions. Rabbis are pleased that science seems to support the Cohen tradition of a common ancestor, but some worry about a litmus test for individuals. For now, however, ancient custom still determines Cohen status.

not seen elsewhere in extensive databases in Michele's lab.

"Basically it's just taking two population sets and comparing them," she says, pausing to lean on her shovel. "The living and the dead."

Unfortunately here in Tzanimacabaj all doesn't go well. Four days of ferocious digging fails to locate the bodies. The villagers and crew are deeply disappointed, but there is no time to mourn this setback. We return to Guatemala City, where some of the hundreds of skeletons already exhumed from other sites are laid out on tables in the residential garage that serves as a laboratory, awaiting analysis.

The next day I find Michele bending over a skull, pulling out a tooth with a pair of pliers. Written in black ink on the cranium is the catalog number SAQ IIIE-FI-2. It indicates precisely which specimen this is and which massacre it came from. But it is not quite the same thing as a name. Convicting someone in court of the murder of SAQ IIIE-FI-2 will be difficult. It is hard to pray for SAQ IIIE-FI-2 if you are his mother. Michele slips the tooth into a resealable bag to take back to her lab.

"There is a saying in forensic anthropology that every skeleton has a voice," says Michele. "We are using DNA to express that voice."

A few days after I return from Guatemala, an eagerly awaited package arrives for me from Oxford, England. Inside is a small conical brush. Following instructions in the letter enclosed, I rub the brush gently on the inside of my cheek for a minute. I place the brush carefully in a provided envelope and post it back to my correspondent, Eileen Hickey, a geneticist at the University of Oxford. If the DNA on the brush is suitable for analysis, I will soon be reunited with an ancestor across an astonishing expanse of time. It strikes me as even more astonishing that this introduction can be conducted through the mail.

Hickey and her colleagues use mitochondrial DNA to sort out when and how the ancestors of modern Europeans first populated the continent. Unlike DNA in the nucleus of the cell, mitochondrial DNA is inherited only from one's mother. The letters of its code are thus passed down unmixed and unchanged from one generation to the next, except for random mutations that rarely affect its function. Because these mutations occur at a known rate and much more frequently than in nuclear DNA, mitochondrial DNA can serve as a clock to time events in the distant past. Compare any two persons' mitochondrial DNA, and the differences between them reveal how long ago they shared an ancestor.

As an American of European descent, I have a mitochondrial mother back in time whom the Oxford researchers might be able to identify. They have already come up with some remarkable findings.

According to Martin Richards, another geneticist on the Oxford team, the ancestors of living Europeans colonized the continent in three main waves. Most Europeans descend from a chain of mothers and grandmothers going back to the hunter-gatherers of the late Upper Paleolithic, some 11,000 to 14,000 years

THE FIRST INDIANS? Partha P. Majumder of the Indian Statistical Institute is using DNA from blood samples (right) taken from 30 different ethnic groups, including members of the ancient Oraon tribe (left), to build a model for the peopling of the subcontinent. His data suggest that the first populations arrived from Africa, then rapidly expanded and diversified. Genetic studies may solve riddles of human origins and migrations.


Fahndungsliste für Kapitalverbrechen

A HEALING HAND, Icelandic surgeon Thorvaldur Ingvarsson (left, at left) replaced Ragnheidur Magnúsdóttir's hips and knees and co-discovered a genetic link to osteoarthritis, a disease that also struck ten of Magnus Gudmundsson's sixteen siblings (below left). A private company will soon win the right to survey Icelanders' DNA, making the nation a living lab. The novel project spurs hope for new cures and sparks debate about privacy and profit.

ago. About 10 percent trace their mitochondrial ancestry even further back, to the original colonization of Europe by modern humans some 50,000 years ago. The most recent group came out of the Levant about 8,000 years ago, following paths through central Europe and along the coast of the Mediterranean up to Britain. These people were early farmers, but they account for only one out of every five ancestors in the European gene pool.

"It is not true to say that the farmers overwhelmed the indigenous hunter-gatherers," says Hickey, addressing a piece of conventional wisdom. "Most of us who call ourselves Europeans will have had ancestors who were here long before the advent of farming."

A couple of weeks after mailing my DNA across the Atlantic, I find out that it falls squarely into the common baseline group against which more unusual variants are compared. Along with some 50 percent of Europeans, I descend from a hunter-gatherer woman who lived in the late Ice Age, perhaps a member of the Magdalenian culture that flourished in western and central Europe and is known best today for its cave art. She is not my only ancestor from that time, of course. But I'm glad to know her, and proud to have her living on in my genome.

TODAY SCIENTISTS all over the world are using mitochondrial DNA to re-create the migrations of other ancient peoples across Africa, the Americas, and everywhere between. It is important to keep in mind, however, that the exquisite diversity in our mitochondrial code that allows us to trace these events is a classic exception that proves the rule. In most of the rest of our genes—99.9 percent of them—every human being alive is exactly the same. Moreover, most of the variations in the remaining one-tenth of a percent don't bunch up into geographic regions or racial groups but instead are spread around the globe. Put another way, the snips and snippets of code that taken together make one person unique are scattered about in other unique genomes all over the world, binding all of us in a splendid tangle of interrelationship.

That tangle doesn't begin at our evolutionary branch but spreads up from far below. All the anatomical differences between human beings and chimpanzees, and even the hallowed uniqueness of human cognition, may in fact arise from slight changes in a few genes regulating fetal development.

Nine-tenths of our genes are identical to those of a mouse (a congruence particularly pleasing to geneticists, since lab mice are well studied and far more readily dissected than people). More than a third of the genes of the lowly nematode worm *Caenorhabditis elegans* are shared with the exalted primate *Homo sapiens.* Genomically speaking, even bacteria are our cousins in code.

The last and most powerful secret revealed by our genes, in fact, is the indisputable unity of everything alive. □

Check our online photo gallery at *www.nationalgeographic.com/2000/science/gene* for the stories behind Karen Kasmauski's pictures in this article.

VALLEY OF THE MUMMIES

BY DONOVAN WEBSTER

PHOTOGRAPHS BY KENNETH GARRETT

DOMINATED BY GREEKS, THEN ROMANS, EGYPT ABSORBED THE ARTS AND GODS OF HER CONQUERORS. ARCHAEOLOGISTS HAVE DISCOVERED A VAST MUMMY CEMETERY IN THE WESTERN DESERT, WHERE HUNDREDS OF BURIALS RECORD ANCIENT CULTURES IN TRANSITION.

Staring eyes and spiral curls typical of Greek portraits join traditional Egyptian motifs on this gilded mummy—one of 43 found in a single tomb.

Sometimes in modern archaeology, despite its high-tech hardware and increasing knowledge of ancient cultures, the best tool any archaeologist can have is good luck. Well, that and a well-placed donkey's hoof. It's precisely this combination that led scientists to one of the largest concentrations of mummies ever found in Egypt.

The year was 1996. At an isolated oasis called Bahariya (Ba-ha-REE-ya), more than 200 miles southwest of Cairo, a local man who guarded the tumbledown 2,300-year-old temple of Alexander the Great was headed to work on his donkey.

As the guard and his mount crossed the desert beneath a withering sun, the improbable happened. Half a mile from the temple the donkey's hoof literally fell *through* the sand.

"The guard got off his donkey," Zahi Hawass tells me. "He helped the animal up and looked into the hole that had been created. Inside he saw a tomb."

Hawass, director general of the Giza Pyramids, Saqqara, and the Bahariya Oasis, is a sturdy, energetic man with piercing eyes and a leonine grin. "By law," he continues, "the area had to be isolated and assessed by archaeologists. And this is what we have. . . . " Hawass lifts his red-shirted arm and motions across the desert, where at least 150 rectangular indentations the size of school buses dimple the sand. "We're finding that each of these depressions is a tomb," he says. "There have been Greco-Roman mummies in every one we excavate. Mummies everywhere! In fact, we've decided

to call this place the Valley of the Mummies."

In the desert around us workers use mattocks and bushel baskets to remove sand from three tombs, part of a cemetery built during Egypt's Greco-Roman period, when the Greeks and later the Romans controlled Egypt from 332 B.C. until the fourth century A.D. It was roughly 2,800 years after the peoples along the Nile in Upper and Lower Egypt were unified. In the centuries that followed, Egypt became one of the most advanced civilizations on Earth, developing the technologies needed to build pyramids for their leaders' eternal life.

Short flights of stairs descend into two of the tombs. In each a central hallway leads to burial rooms where individual mummies or mummified families have been interred with their worldly goods for use in the afterlife.

The third tomb is a square pit about 15 feet deep; around the sides burial niches burrow into the walls. In one of those niches workers found a mummy that Hawass has nicknamed Mr. X. The mummy, wrapped tightly in resin-soaked gauze as brown as dry tobacco, is an odd mixture of human form and austere sculptural lines. The longer I look at him, the more I can't get past the idea that he lived before Muhammad, and maybe even before Jesus, walked the Earth. Yet there he is—a silent messenger from another world.

A flurry of activity draws Hawass to a nearby tomb, where diggers have just uncovered a family of six gilded mummies, including two infants. Hawass hurries down into the crypt and, with a tiny brush, carefully cleans the sand from one of the adults, revealing a face with mother-of-pearl eyes.

"We estimate that only 30 percent of what the ancient Egyptians left behind has been discovered," Hawass says later. "So when I come to a place like this, I'm always excited. I love digging into the unknown, and we've only begun our work here. I'm sure we'll learn a lot more about Egypt during the Greek and Roman periods, a time in our history not completely understood."

Alexander the Great launched Egypt's Greco-Roman period in 332 B.C. After conquering parts of western Asia, the Macedonian general was welcomed in Egypt by a people politically weary after several hundred years of unrest and occupation by outsiders.

The mixing of Greek (and later Roman) influences with a still rich Egyptian culture helped set social and religious change spinning around the Mediterranean. In this newest period of vibrancy the Egyptians' styles of dress and sculpture worked their way to Greece and Rome, while Egyptian gods and demigods mingled with their counterparts in Greek and Roman mythology. The mother goddess Isis would eventually have temples built to her in the land of the Caesars, while

CARVED into stone beneath the sands of Bahariya Oasis, a multi-chambered tomb (left) may have been used by a single family for two centuries. The entire ancient graveyard may underlie as much as 14 square miles on the edge of the oasis. Its burials span perhaps 600 years—from Alexander the Great's conquest in 332 B.C. until the fourth century A.D., when Rome ruled Egypt.

ETERNAL VARIETY

AN UNADORNED MUMMY (above) named Mr. X by Zahi Hawass, director general of the Giza monuments (below), may be one of the cemetery's earliest occupants. A clay coffin (right) dates from the Roman period. By A.D. 350 Christianity flourished in the Mediterranean world, and the practice of mummification began to disappear.

many Greco-Roman gods and heroes would be honored in temples throughout Egypt. Here at Bahariya temples honored both Alexander the Great and the Greek demigod Heracles.

For several centuries after Alexander, Egypt thrived. During this period of political stability its international trade flourished, its rulers imported more efficient ways to cultivate food, and its population boomed. No longer preoccupied with defense, its people could spend more time enjoying life's beauties and preparing for the hereafter. In the days of the pharaohs only royalty and the ruling elite could afford funerary face masks; now the upper class and possibly the middle class commissioned them as well. Artisans also fashioned cartonnages: rectangular chest plates in gilded plaster and linen that reflected the deceased's place in society.

But as ancient Egypt flowered again, the reasons behind some of its time-honored practices were forgotten, discarded, or altered. "By the Greco-Roman period," says Nasry Iskander, general director of conservation at the Egyptian Museum in Cairo, "in the ways of mummification most Egyptians were merely going through the motions. They were carrying on this tradition, but maybe they could no longer remember why."

To prepare the deceased for the afterlife during pharaonic times, funerary workers removed most internal organs, then sterilized the body and dried it by packing it—inside and out—with natron salts. About 40 days later the body was wrapped in linen strips, placed in a series of wooden cases and an outer stone coffin, and laid in a crypt. The body faced east to greet the rising sun in symbolic rebirth.

"But look here," Iskander says, pointing at the crypt. "Very few of the mummies so far discovered here are even buried in coffins, and their tombs are not all oriented facing east in the traditional style. And sometimes two, three, or more mummies have been piled in a tomb intended for one."

Other aspects of the burials differ as well. None of the 105 mummies excavated so far at Bahariya were buried with canopic jars, common in tombs

NEW GODS AND OLD

ITS GAZE FIXED on the next world, the golden covering of a female mummy (left) was probably selected from a local workshop. The roster of deities thought to control daily events and eternal fate grew longer through the Greco-Roman period. Part dwarf, part lion, the Egyptian god Bes (right) guarded pregnant women and newborns. Among the ruins of a temple named for Alexander the Great, excavators found statues of a goddess figure blending Egyptian Isis and Greek Aphrodite (above, at left) and Osiris, Egypt's lord of the underworld, at right. A clay mother and child (above right) hints at later Christian themes.

from pharaonic times. The jars, which held the deceased's lungs, stomach, intestines, and liver, were decorated with paintings or reliefs of the four sons of Horus, the powerful sky god. By Greco-Roman times the jars had been replaced by symbolic drawings of the four sons on the cartonnage.

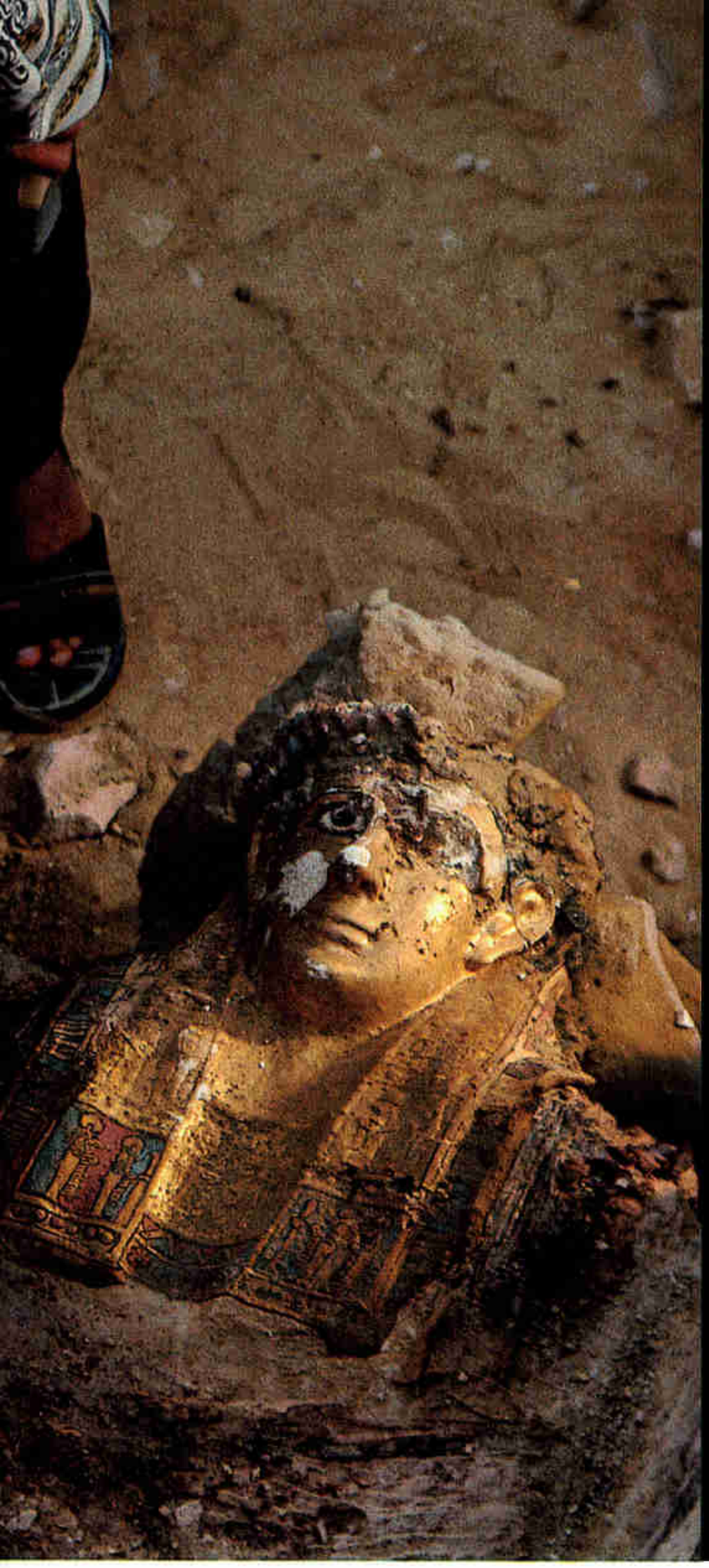
Iskander believes that these changes indicate a loosening of traditional religious practices, which may have been diluted by the new beliefs imported by the Greeks and Romans. The changes may also be a sign of increased pressure on embalmers, who—with the upper classes clamoring for their services—had more bodies to prepare for the afterlife.

In the tomb at our feet two archaeologists brush the final layers of sand from Mr. X. Then, before getting face-to-face with the mummy, they stop to pull on surgeon's masks.

"It's always preferable to wear masks when you excavate freshly opened tombs," Iskander says. "Masks keep out ancient dormant viruses or bacteria that might exist with the mummy. If you breathe the viruses or bacteria in, the heat and moisture from your lungs can revive them. If your immune system isn't prepared, you can die. Fast. In days or a week. It has happened a few times. And while not the fabled mummy's curse, it's real enough."

The uncovering of Mr. X brings Hawass

DONOVAN WEBSTER, a frequent contributor, lives outside Charlottesville, Virginia. KENNETH GARRETT, also a Virginia resident, has photographed archaeological digs from Chile to China.



A GOLDEN ETERNITY

ELABORATE MUMMIES proclaim a family's status (left). Decorated breastplates show these people could afford a gilded afterlife. But painted details (above) mystify experts. Who are the Egyptian figures crowned by solar disks? Is the running image, below, the Greek god Hermes, escort to the underworld? Years of excavation ahead may provide the answers.

over from another part of the excavation. As he looks into Mr. X's tomb, Hawass bows his head and removes his hat, holding it by its felt brim. After a moment of quiet he says that each time he disturbs a grave, the scientist inside him wars with the human being. Because of these conflicting feelings he usually favors excavating as few tombs as possible at any site.

"In one way," he says, "I find this so exciting. Who can predict what Mr. X will tell us of his world? But I also dislike disturbing mummies, as they have started the long journey into the afterlife, and we are intruding. So I ask Mr. X's forgiveness, that he may teach us something of his world. Then I will return him and his goods to this place so he can go on to paradise."

As the excavation continues, Hawass, Iskander, a dozen experts, and 70 laborers gather more information about the Valley of the Mummies and Egypt's Greco-Roman period. The graveyard may stretch much farther than originally thought—perhaps three or four miles on a side. Ancient Bahariya may have been home to 30,000 farmers, winemakers, and artisans. And the cemetery is more densely packed with tombs than the scientists first believed. One afternoon when team members back a four-wheel drive next to the site's guardhouse, the rear wheel plunges through the ground, revealing yet another tomb. Past surveys of the surrounding desert have unearthed a temple dedicated to Bes, the Egyptian god of pregnancy and newborns, as well as the ancient courtyard, towers, and

ramparts of a military garrison for Greek and Roman soldiers.

The scientists have also discovered that Bahariya Oasis is drying up. During the Greco-Roman period the water table lay only 15 feet beneath the surface; today, wells must be sunk 4,500 feet to hit water.

Throughout the oasis workers have unearthed more than 7,000 artifacts. One afternoon Hawass shows me the provisional museum at the *taftish*, the antiquities headquarters in nearby Bawiti where many of them are stored. Inside a series of secure buildings near the center of town, curators welcome Hawass like royalty. We walk to a locked room where three mummies rest in glass cases monitored for temperature and humidity.

"We found these mummies last year," he says, "but we realized we'd need a very thorough excavation, so we closed the tomb until now. These came from one of the excavations we worked on today."

One of the mummies wears a headdress with a gilded scene of a flying falcon—probably the god Horus, an ancient symbol of royalty. All three have gilded cartonnages that are brightly painted.

"You can tell by the gold, the flying Horus, and the cartonnages that these people were rich," Hawass says. "They were probably from a higher class. They might have been overseers of the desert, managing the farmers who cultivated crops. We have found evidence that Bahariya was a large government wine-making center."

The mummies' funerary masks, with their curls, long aquiline noses, and wide eyes, reflect the influence of Greek sculpture. And instead of the solid gold of pharaonic masks, each of these masks is made of plaster coated with a thin layer of gold.

The reason for the change? Before the arrival of the Greeks, Hawass says, Egyptians bartered for goods and services instead of using money. Then the Greeks introduced coinage, which eventually led to a wider distribution of wealth. More people could afford to buy burial masks, so workshops began producing more of the gilded variety—masks that had the look of royal versions but not the price.

Other glass cases hold a dozen unusual foot-high statues of wailing mourners found with one gilded mummy. Hawass believes you can tell how important people were by the number

CONQUERORS' COINS could be useful in a netherworld infiltrated by their gods. Most of these bronze pieces from a Bahariya tomb are from the Roman period. Guarding trade routes linking the western oases, a Roman fort (right) embodies the centuries of foreign rule that recast Egyptian life—and afterlife.

"WE'VE ONLY BEGUN OUR WORK HERE. I'M SURE WE'LL LEARN A LOT MORE ABOUT EGYPT DURING THE GREEK AND ROMAN PERIODS."

of symbolic mourners buried with them.

We step through another door to a brightly lit laboratory where some of Bahariya's antiquities are repaired or cleaned, revealing the history beneath two millennia of sand and dirt. Hawass picks up a four-inch-high faience falcon, fired to a rich greenish blue. The bird is perfect. Its individual feathers are visible and detailed. Its wings fold to a graceful V behind its back; its hooked beak looks ready to rip open the next unlucky prey locked in its talons.

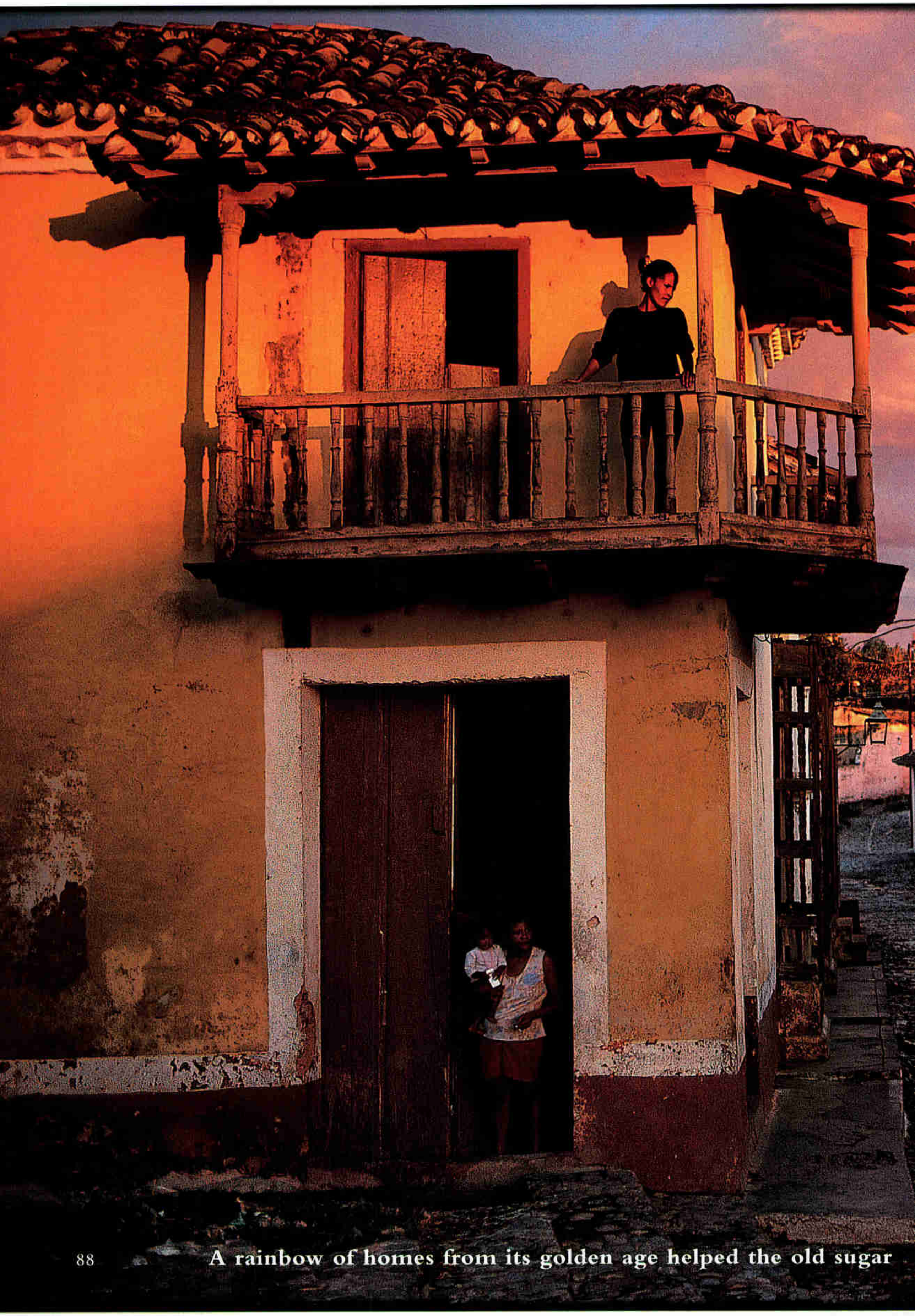
Emanating both elegance and antiquity, the falcon is one of the most beautiful objects I've ever seen, and I can't help but wonder who was the last person in ancient times to hold it. Who, like me, regarded it as so perfect that he wouldn't want to depart for the afterlife without it? Did he die with it in his hands?

Before I can ask these questions, Hawass puts the sculpture back on the table and lifts an eight-inch square of limestone etched with concentric circles. "Look at this," he says, handing me the slab, heavy as a brick. "It's an early board game found in the tomb with the gilded mummies. Can't you imagine the ancient Egyptians playing this very game?"

The bull's-eye has been scooped out, and a small cube of etched limestone—a die—teeters in it. I hold the game gently, careful not to tilt it and roll the die. Who made this? And how many days and nights did they spend huddled over it, immersed in contests full of teasing, bickering, and maybe even wagering?

"There were not the social diversions here that existed in the cities," Hawass explains, taking the slab from my hands and returning it to the table. "So they played games, had parties. Can't you see them eating dates and olives, drinking wine? This is why I love my job so much," Hawass says, pausing to ignite one last smile. "Each time we find an artifact like this, it helps bring a whole world back alive." □

Excavating burial sites: Are we trespassing on sacred ground? Comment online at *www.nationalgeographic.com/ngm/9910.*



A rainbow of homes from its golden age helped the old sugar

Cuba's Colonial Treasure

town of Trinidad gain status in 1988 as a UNESCO World Heritage site.

Friends and family visit streetside in this living monument, which has embraced generations of Trinitarios for almost 500 years. "There's no other place like it in all of Cuba," says an elderly resident. "My wife and I were born here, and we love it."

By A. R. WILLIAMS • *Photographs by* DAVID ALAN HARVEY
BOTH NATIONAL GEOGRAPHIC STAFF

Tucked between the Sierra del Escambray and the Caribbean Sea, the site of Trinidad was originally home to the native Taino, who panned for gold in nearby rivers. Conquistadores founded the Villa de la Santísima Trinidad, Spain's third settlement in Cuba, in 1514. Amid streets laid out around a spacious plaza, Hernán Cortés organized men and supplies

for his conquest of Mexico. With the wealth of the Aztec eclipsing anything found here, Trinidad became an outpost of smugglers and pirates. The Taino were virtually exterminated by 1550.

Boom times came in the late 18th century, when profits from sugar—grown in the Valley of the Sugar Mills (above)—bankrolled the construction of fine houses and buildings such as the former Convent of San Francisco, whose tower is the town's most recognized landmark (left). In 1689 the town had 980 residents; by 1755 it had almost 6,000. As the plantation era faded, Trinidad turned into a backwater once again. The railroad didn't reach here until 1919 and a highway not until the 1950s. Isolation preserved the colonial heart of the town, where 6,000 people live today. Protected by law, the old neighborhoods are being restored.

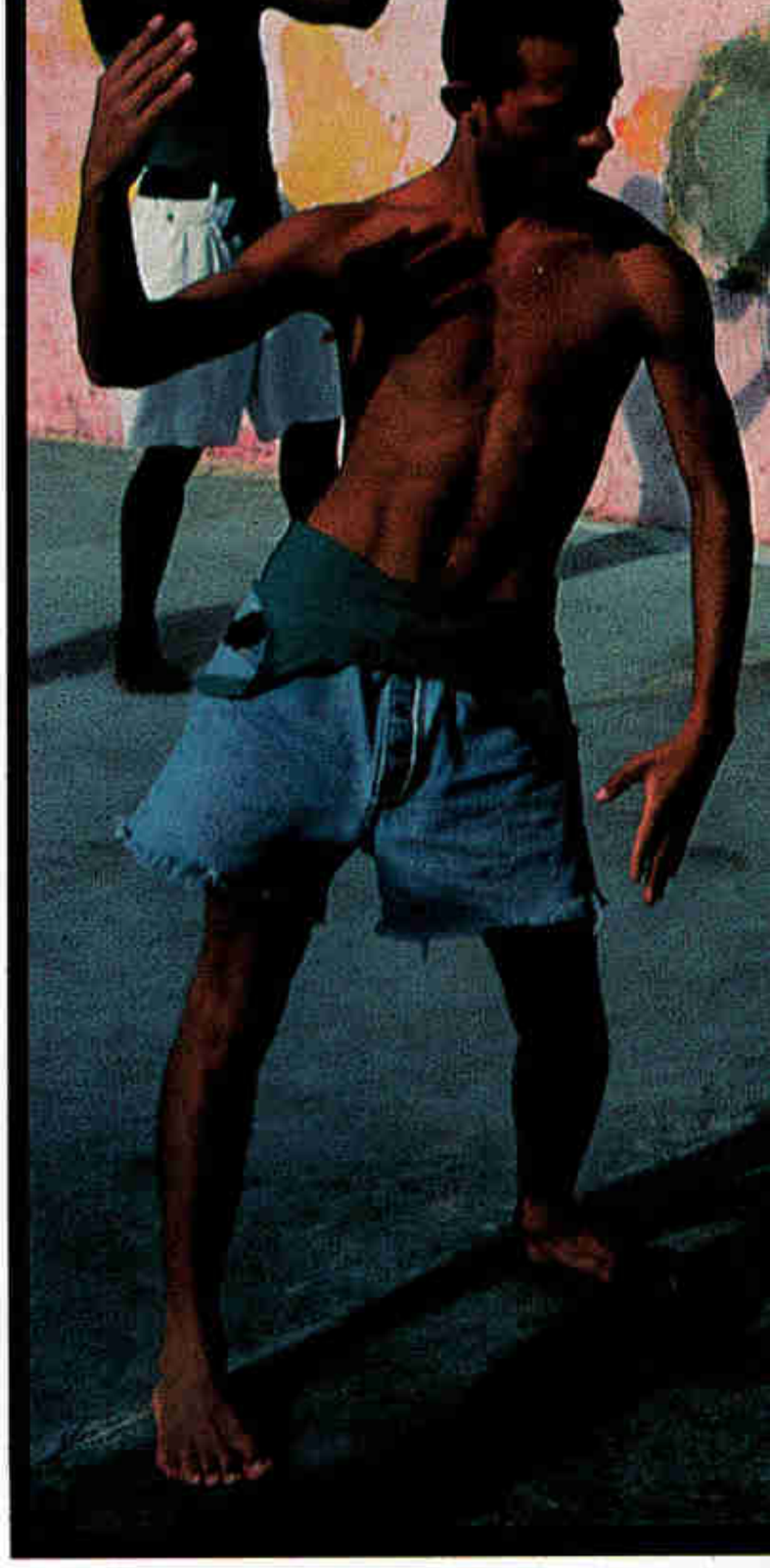

315

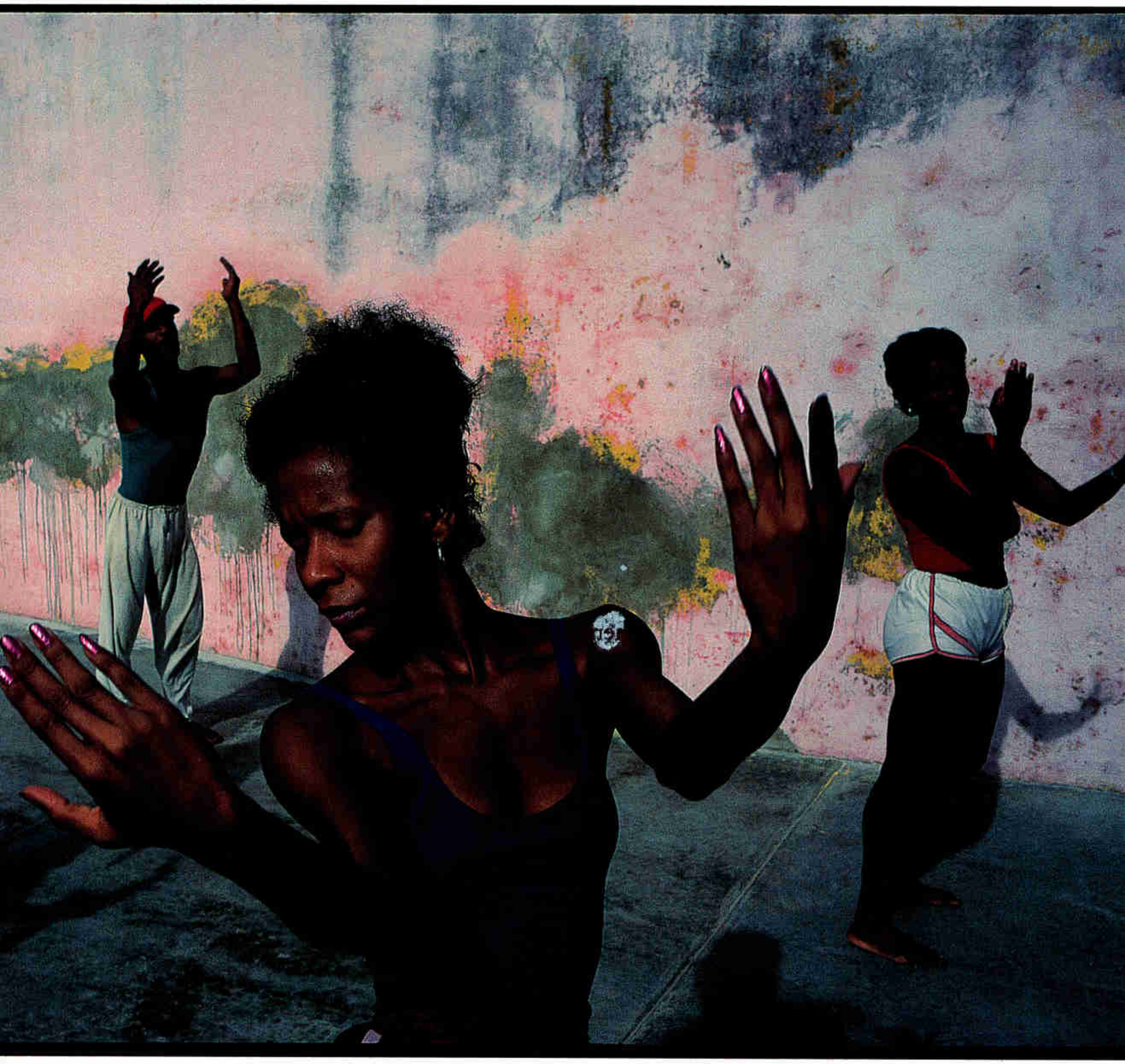
Along streets resonant with the clip-clop of horses' hoofs and the squeak of bicycles, life moves at a pace from decades past. A young man tinkers with a U.S. jalopy by the curb. An older couple watch the passing parade from their front door. Sharing news with a customer, Orestes Ramírez Soa scans an issue of *Granma,* the official state paper, which he bought from a vendor at his open window. Ramírez Soa gives an old-fashioned shave—hot lather, applied with a brush, and quick deft strokes with a straight razor. The experience was so soothing for photographer David Harvey that he fell asleep on one of his regular visits. Ramírez Soa's equipment is wearing out though. Giving Harvey a sketch of barber's shears, he asked, "Do you think you could bring me a pair like this when you come back?"

Coming of age at 15, Yunisleidis de la Cruz Mendoza Lozano shows off her party dress near her grandmother's home in Tres Cruces, Trinidad's oldest neighborhood. Like all Cuban girls marking this passage, she will be feted as lavishly as her family can afford.

Music fills every corner of this culturally rich town. In an empty courtyard on weekday mornings the Trinidad Folkloric Ballet moves to Afro-Cuban rhythms, preparing their repertoire for audiences at home and abroad. "Some of our dance traditions are similar to those in other parts of Cuba, but others are specific to here," says Gisela Zerquera Calderón, the group's director. "We think it's important to keep them alive and show them to the world."

Visitors from around the world come mostly as day-trippers in tour buses. Around the main plaza, where a musician passes the parish church (above), they invariably find street bands playing Cuban songs on conga drums, clay pipes, a guitar, and bass. Music and dancing are even part of a child's birthday party—after cake and candles, a clown, and games.

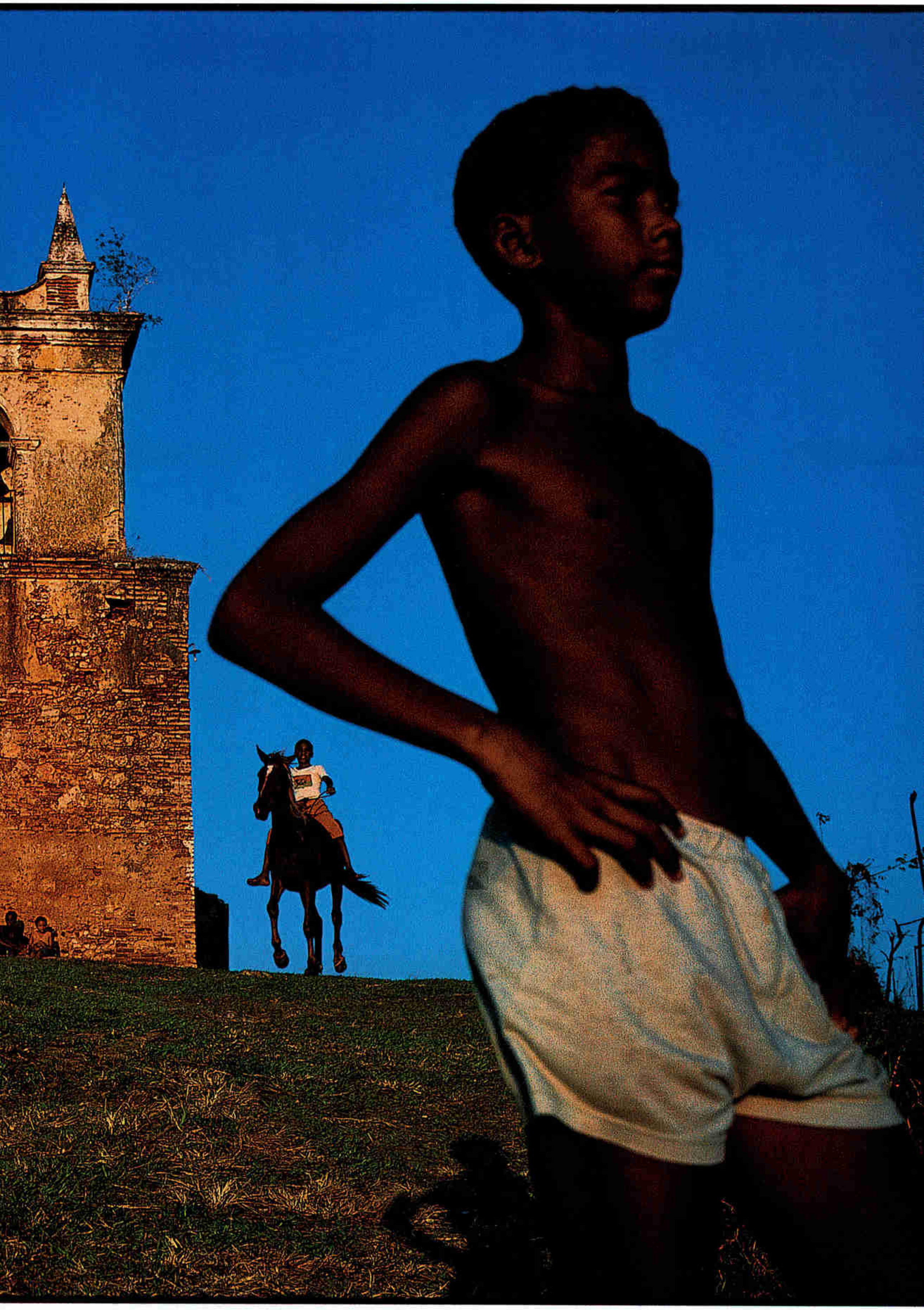


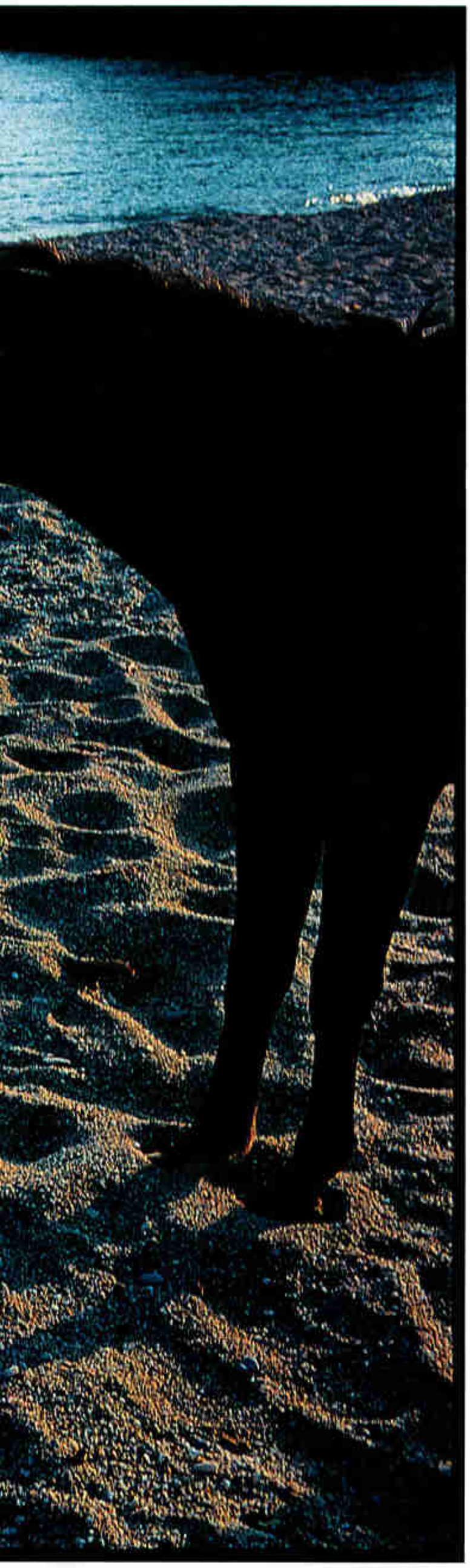


Parked overnight on a porch, a horse will soon be put to work. With public and private vehicles scarce in Cuba, Trinitarios continue to rely on horses and burros to carry children to school, take vendors on their rounds, and even pull the trash-collection cart.

A glimmer of elegance from the time when Trinidad was a cosmopolitan center of culture and trade lives on behind a few of the shuttered windows along cobbled streets (above). Elsa Zayas Mendoza (below) shares one of the grand 18th-century houses with her husband, a retired lawyer. Rosa Orbea Cerrillo (left, at left) and her husband run a bed-and-breakfast in another. In their best room she prepares her niece Annalien for her 15th-birthday photographs. "I love that girl as if she were my own daughter," she says. "I'm very protective of her." With eyes fixed on the future, Annalien dreams of studying acting in Havana. Her aunt tells her the dream will keep until she finishes school in three years. "This is a small, provincial town, and she has never been anywhere else. She's just not ready to take on the big city yet."

The oldest church still standing in Trinidad—Nuestra Señora de la Candelaria de la Popa, built in the early 1700s—needs restoration and is closed to the public. Yet it still attracts townspeople who gather at the hilltop site to watch the sun set.





The sea opened Trinidad to the world, bringing in conquistadores, sugar traders, and visitors such as 19th-century naturalist Alexander von Humboldt. Today its unspoiled Caribbean shore draws a growing number of tourists, who come mostly from Europe, Canada, and the rest of Latin America. For locals, getting to the beach is as easy as a slow cruise via classic car or four-legged transport. Mountain streams on their way to the sea have their own appeal.

Do Trinitarios realize how lucky they are to live here? "It's easy to forget how special this place is as we go about our daily lives, I guess," says a guard in one of the town's museums. "But all we have to do is look around to be reminded of its beauty." □

See more of David Alan Harvey's photographs of Cuba at *www.nationalgeographic.com/photography/harvey.*

MYSTERY ON

BY CONRAD ANKER

MALLORY & IRVINE RESEARCH EXPEDITION/LIAISON

IT WAS A BRIGHT cold morning on Mount Everest. Sunlight coming over the Northeast Ridge made the rarefied air at 27,000 feet feel warmer than the 0°F it was. Seven thousand feet below in Tibet, pockets of meltwater shimmered on the terminus of the Rongpu Glacier, which bunched like a carpet as it pushed through the valley.

After an hour or so of searching I had found two bodies far apart on the lower edge of a snow terrace below and to the west of the standard route up the Northeast Ridge. Both were grotesquely twisted and folded, suggesting they had suffered long, violent falls. Their faded down suits indicated that they had perished during the past few decades. They weren't the climbers I was seeking.

Members of the Mallory & Irvine Research Expedition examine a tent (above) possibly dating from a 1933 British expedition that tried, in vain, to locate the legendary climbers' remains. The 1999 team found an oxygen bottle at about 28,000 feet, evidence of Mallory and Irvine's progress toward the summit.

EVEREST

On June 6, 1924, George Leigh Mallory, at left, and Andrew Irvine set out with experimental oxygen bottles from Camp IV high on Mount Everest. Two days later they vanished into a bank of clouds. Were they the first to stand atop Everest? The discovery of Mallory's body answers some questions, but the riddle endures.

of Climber George Mallory, Missing for 75 Years.

MALLORY & IRVINE RESEARCH EXPEDITION/JIM FAGIOLO, LIAISON (OPPOSITE); AUDREY SALKELD COLLECTION

I was on the mountain that day, May 1, 1999, as part of an expedition seeking clues to the fate of George Leigh Mallory and Andrew Irvine, the legendary British climbers who disappeared on the Northeast Ridge on June 8, 1924. Not far from there a British Expedition in 1933 discovered an ice ax with marks suggesting it had belonged to Irvine. Below where the ax was found, a Chinese climber, Wang Hongbao, in 1975 reported seeing a weathered body he described as an "English."

When I finished searching the terrace's lower edge, I took off my crampons to start back up a steep incline of loose rock and smooth slabs that had been exposed after a winter with little snowfall. A patch of white, different from the snow and as bright as marble, caught my eye. I realized it was a body. Bleached white skin. A hobnailed boot. A braided climbing rope. No nylon.

In my slowed-down, dreamlike state at high altitude, I did not immediately recognize who this was. I sat down next to the body, studying the tattered edges of his wool sweater and cotton wind jacket. He was facing uphill on his front, both arms outstretched, as if grasping to arrest his slide. His left leg was crossed over the right, which was broken above the ankle. I realized at last that I had found one of the two people for whom we'd been searching.

Because our radios could be monitored by dozens of climbers, our team had agreed to use coded messages. "The last time I tried a boulder problem in hobnailed boots I fell off,"

This is CONRAD ANKER's first writing assignment for the magazine, but he appeared on the cover of the February 1998 issue as a lonely figure on a precipice overlooking ice-choked mountains in Antarctica. He has climbed peaks around the world, notably in the Himalaya and Patagonia and on Canada's Baffin Island.

THOMAS H. POLLARD (BELOW); AUDREY SALKELD COLLECTION

EVER THE DASHING ENGLISHMEN, Mallory (above, at left) and Irvine joined forces to take advantage of Mallory's experience on Everest and Irvine's mastery of oxygen bottles. Their climb was Mallory's third time on the mountain in four years. "We've got to get up this time," Mallory wrote to his sister. The oxygen bottle and an ice ax found in 1933 place Mallory and Irvine close to the First Step, but still below the formidable Second Step, a 90-foot-high rock wall that leads to the summit (right). Author Conrad Anker (left), who found Mallory, climbed the Second Step on his way to the top last May.

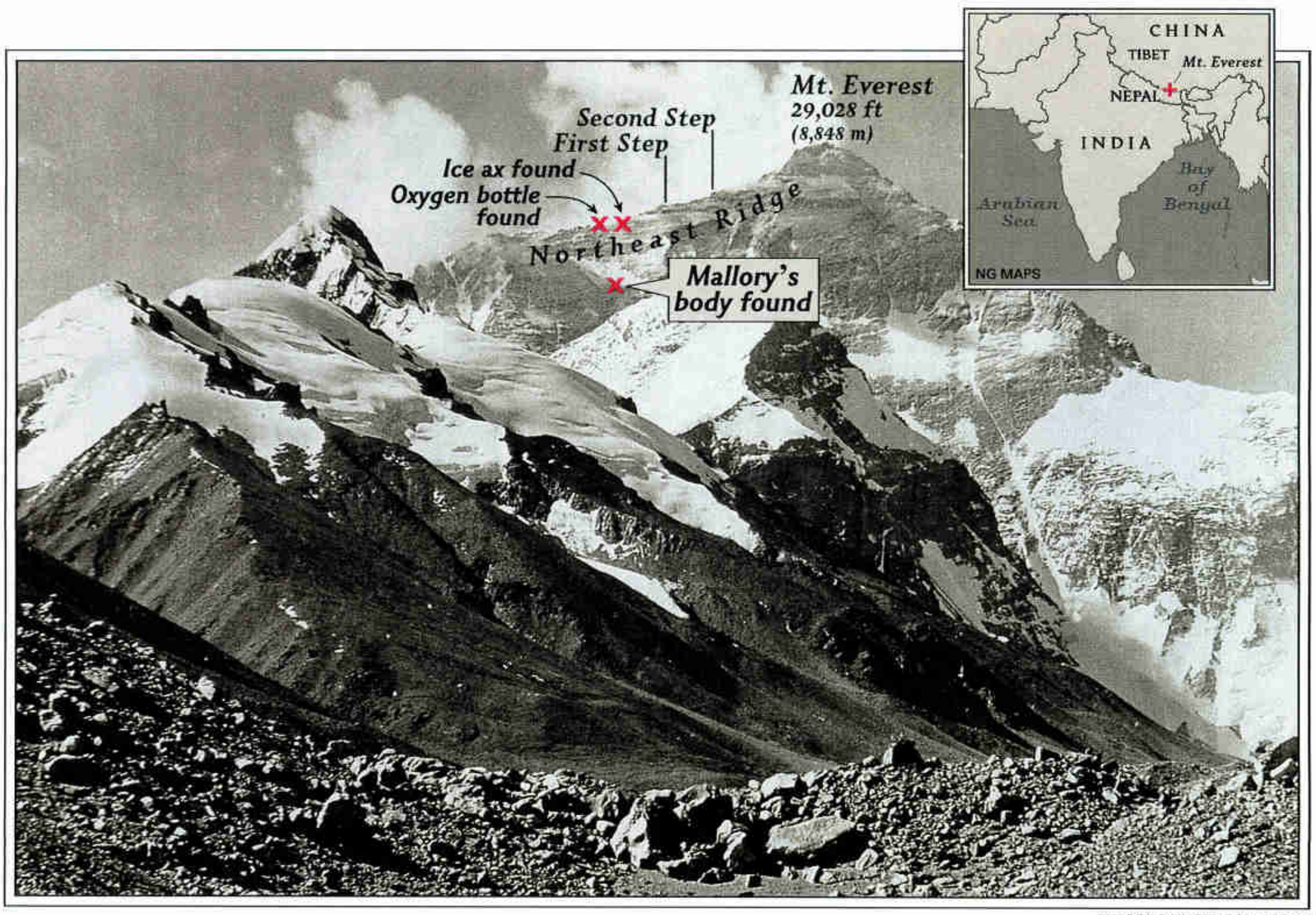
I radioed to Jake Norton, Dave Hahn, Andy Politz, and Tap Richards, who were fanned out across the terrace above me. Jake heard me say "hobnailed" and instantly looked down to see me waving. I tried the others again, asking them to join me for "tea and Snickers." My third call was for a "mandatory group meeting." Soon all four were descending toward the final resting place of George Leigh Mallory.

"He's frozen solid to the rocks," Jake said, as he and Tap carefully chipped at the ice with an ax. There was no way to turn him over. Gently cutting off his shirt collar, Jake held out the label so the rest of us could read the neatly stitched name, "G. Mallory." Reaching under the body, he removed a pair of sun goggles from a chest pocket, from another pocket a handkerchief monogrammed "G. L. M." Under his right arm, Jake found a broken altimeter, scissors, and a pocketknife. In a vest pocket close to Mallory's heart was a packet of letters from his family.

After we searched the body, we covered it with rocks, Andy read an Anglican committal ceremony, and we left Mallory in peace.

Curiously, Mallory was not wearing gloves. Nor did we recover his 1924 Kodak Vest Pocket camera or any other conclusive evidence to answer the big question: Had Mallory been the first person to stand on top of the world? From what we found with his body and from the difficulties I experienced myself in climbing his route to the summit, I think it's highly improbable, for the following reasons:

■ The route is too tough. When Mallory and Irvine were last seen, they were somewhere near the Second Step, a 90-foot-high wall of rock at 28,300 feet. Two weeks after finding Mallory's body, I tried to free climb this sheer wall much as Mallory would have, avoiding a ladder left in 1975. I found it extremely difficult, even with crampons and modern rock-climbing techniques. Climbing roped together without attaching any gear to the rock—standard procedure in their day—would not have gotten Mallory and Irvine up the Second Step.



AUDREY SALKELD COLLECTION

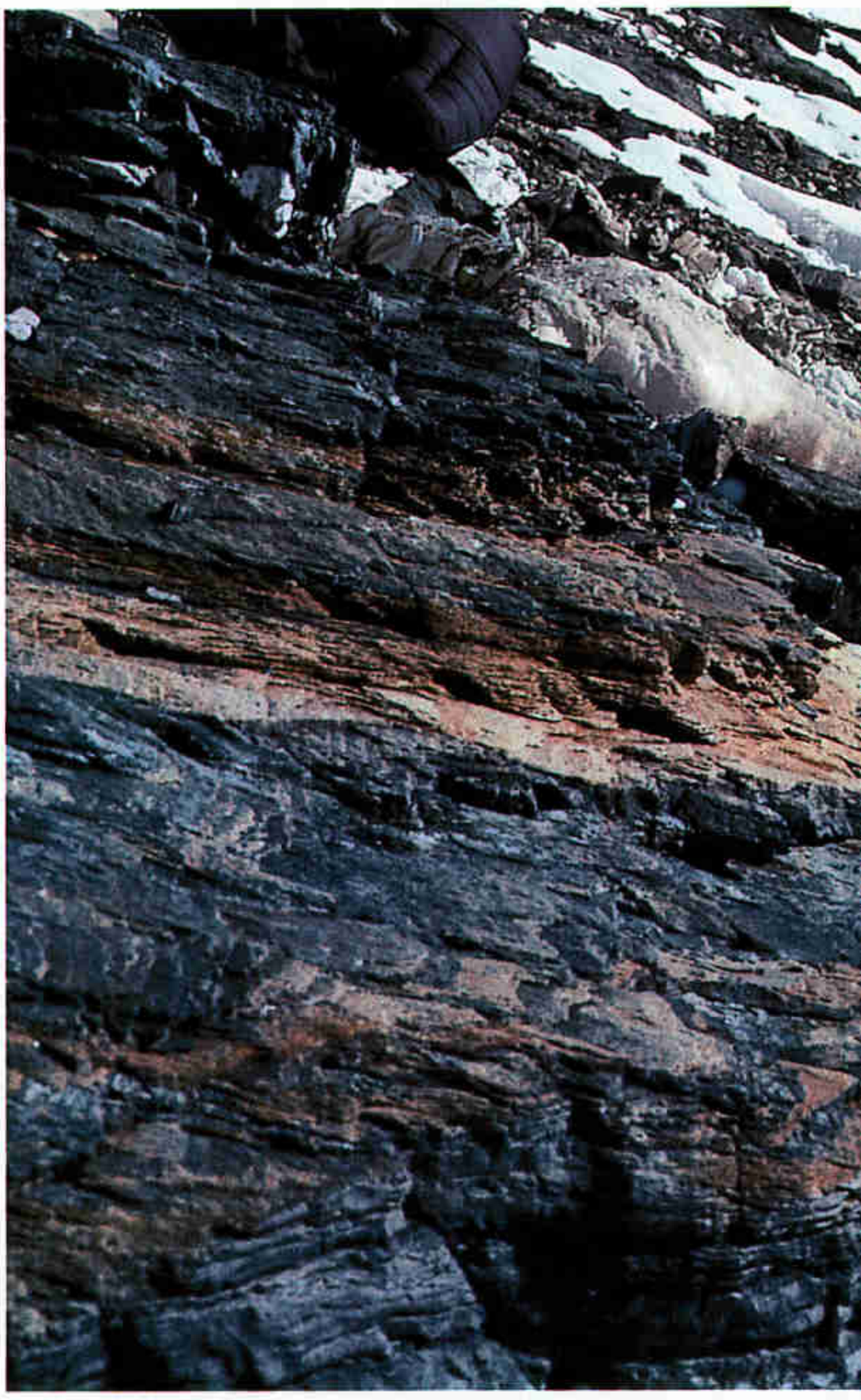
Mallory and Irvine pioneered a route through Tibet to Everest, as seen in this 1924 photograph. Edmund Hillary and Tenzing Norgay first reached the summit, in 1953, via Nepal.

■ Their gear and supplies were insufficient. Without crampons for secure footing and fixed ropes to guide them and aid their descent, Mallory and Irvine would have had to have been superhuman to have summited. Their oxygen apparatus was heavy and prone to malfunction. And their lack of adequate food and drink would have slowed them down and increased their chances for mistakes.

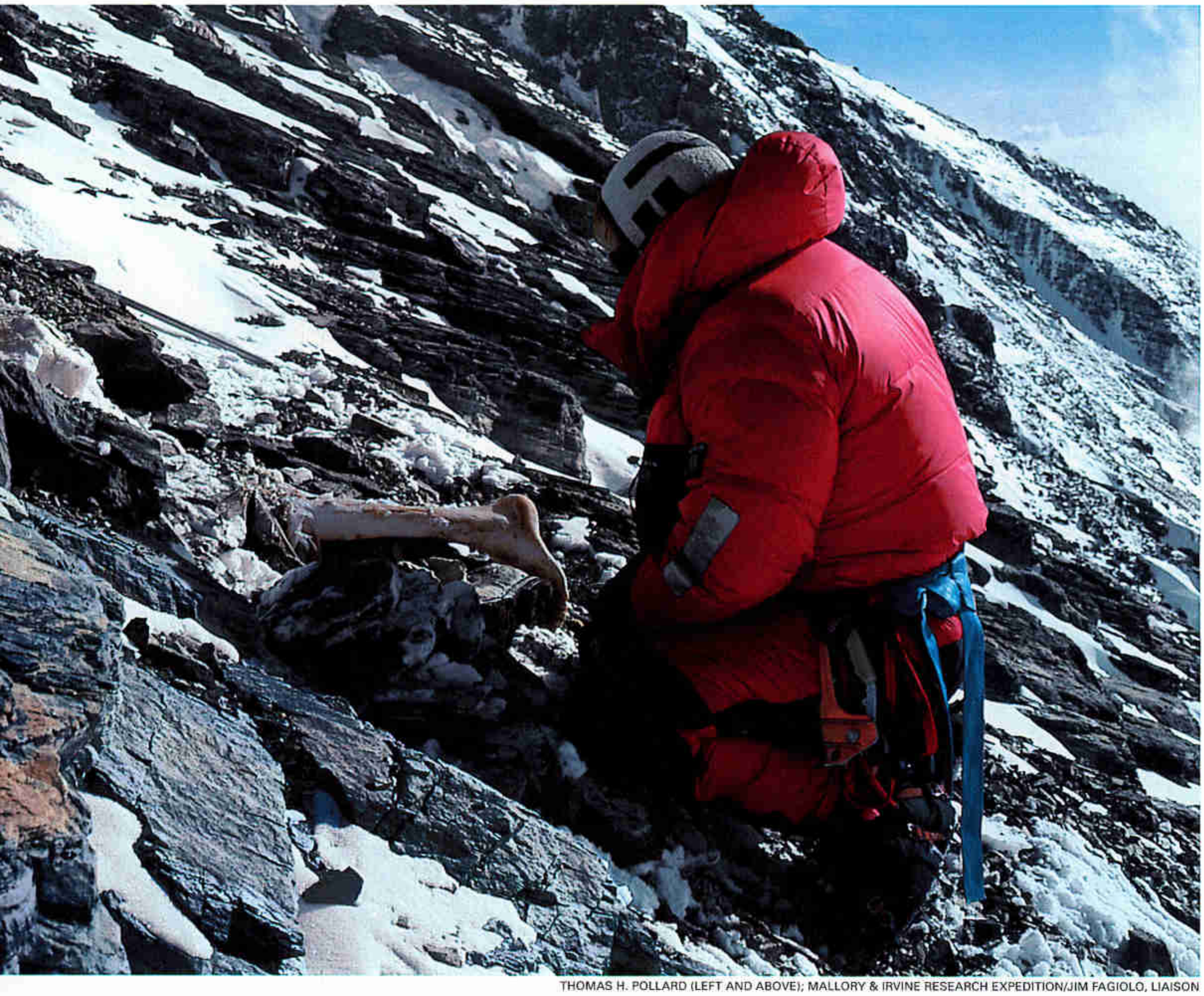
■ The timing was off. They were climbing late in the day. If they had made it to the summit, they would have had to bivouac in the open. But Mallory's nose and fingers were not swollen and discolored by frostbite, which leads me to believe that they did not spend the night outside before dying. To me Mallory's missing gloves are a crucial clue. Having turned back above the First Step, Mallory may have taken off his gloves to grip the steep rock as he descended. I think he probably slipped and pulled Irvine off a ledge. The frayed rope still tied to Mallory's waist may have been cut by an edge of rock, sending him tumbling to the snow terrace, then sliding farther to where I found him.

Calm weather and a light snow season proved lucky for the 1999 expedition. When conditions turned stormy, a Ukrainian climber was stranded near the summit, and the team helped rescue him.

None of this, of course, has lessened my admiration for Mallory and Irvine. The route they pioneered to the Northeast Ridge in the 1920s is the one most climbed today on the north side. For the two of them to have gotten as high as they did with the resources they had is truly amazing. Whether or not they made the summit, they will forever hold a place as heroes on the world's highest peak. □



A Final Resting Place



THOMAS H. POLLARD (LEFT AND ABOVE); MALLORY & IRVINE RESEARCH EXPEDITION/JIM FAGIOLO, LIAISON

"WE EXPECT NO MERCY from Everest," Mallory told a friend before his final expedition. When his frozen body was found, Mallory was lying face down with his left leg crossed over his broken right one. A spare glove (left), boots, goggles, and penknife (below) were found with him. So, too, was his circular altimeter, which once recorded altitude near the summit of his ambition. He had written to his wife: "I look upon myself as the strongest of the lot, the most likely to get to the top." To honor that hope, the team interred Mallory's remains beneath rocks, held a brief burial service, and descended the merciless mountain.

BY PRIIT J. VESILIND • PHOTOGRAPHS BY JONATHAN BLAIR
NATIONAL GEOGRAPHIC SENIOR WRITER

WORLD WAR II IN THE ATLANTIC...
GERMAN U-BOATS...
SECRET CODES... GOLD BULLION...
A RENDEZVOUS AT SEA...
AMERICAN FLYBOYS...
SUDDEN DEATH...
A SALVAGE HUNTER...
THE LUST FOR GOLD...
AND A JAPANESE SUB ON...

THE LAST D

IVE

Shrouded in rust, the Japanese submarine *I-52* cruises into eternity with 112 souls who rode it to the bottom in 1944. It was sunk by American bombers after surfacing to meet a German U-boat.

MARK WAGNER

1998 There's a lot of time to think when you're falling three miles deep into the Atlantic Ocean, because it takes four hours to reach bottom. And I'm mostly thinking, "Lord, let the ballast pumps work this time."

I'm cramped inside a capsule the size of a '57 Buick, a steel-hulled submersible named *Mir 1*, meaning "peace" in Russian. Beside me are Viktor and Igor, compact, self-possessed men, pilot and navigator of one of the world's most efficient deep-ocean diving systems.

There had been trouble on a previous *Mir 1* dive involving a sticky pump valve. The submersible was stalled on the bottom for an hour and a half and finally had to release its emergency ballast of nickel shot to gain buoyancy. I was on a later dive but figured, "*nyet* problem," as the Russians say. No one's been left on the bottom yet.

Our submersible is one of two carried on the oceanographic vessel *Akademik Mstislav Keldysh*. The *Keldysh* now hovers high above us, carrying 90 Russian sailors and scientists and a group of about 30 Americans, some from Cape Verde Explorations, a company formed by project leader Paul Tidwell. He is a salvager from New Orleans and has chartered the Russian ship for six weeks in the deepest private shipwreck expedition in history—nearly a mile deeper than the *Titanic*.

Viktor looks nervous as we sink below 12,000 feet. My imagination, probably. Cold sweat—no, it's condensation—forms on the walls as if the pressure were punching seawater through metal. We pull on heavy jumpsuits against the 50-degree chill. An hour later *Mir 1* settles onto the bottom like an alien spaceship. I check our position: latitude 15°N, longitude 40°W. We're 870 nautical miles from the Cape Verde Islands, 1,130 miles from Barbados, and 17,190 feet straight down.

Somewhere in the murk nearby lie the remains of a 350-foot World War II Japanese submarine, the *I-52*, sunk in 1944 by American aircraft. It carried a load of rubber, tin, opium, quinine, tungsten, molybdenum, and two metric tons of gold bullion bound for the coffers of the Japanese Embassy in Berlin—146 bars in 49 metal boxes, worth more than 15 million dollars today.

For more than 40 years the wreck might as well have been on the moon. It was beyond reach, its location only roughly known and the details of its sinking locked in classified documents.

By the 1990s advances in deep-sea technology had made three-mile depths accessible, but the *I-52* was still a small sliver in a vast space. Was it in one piece? Was the cargo intact? And was its voyage linked, as some conspiracy theorists suggested, to uranium and nuclear secrets?

For Paul Tidwell, a man fascinated with history yet haunted by it, the *I-52* was a puzzle that had become a passion. He knew that with meticulous planning he might find the wreck, perhaps with those 49 boxes of gold bars strewn around it like coins. Or he might find something less tangible that mattered more.

Shuttle to the abyss, the submersible *Mir 2* is lowered from its Russian mother ship, *Keldysh*, for a 16-hour round-trip journey to the *I-52*. Hired by American salvager Paul Tidwell to explore the wreck, pilots from Russia's Academy of Sciences used *Mir 1* and *Mir 2* to take observers to the bottom.

1944 In spring, when cherry trees were blooming near the Imperial Palace, 34-year-old Satonobu Gamo left home in Tokyo on a mission so secret he could not even tell his

PRIIT J. VESILIND, NGS STAFF

For Paul Tidwell, a man fascinated with history yet haunted by it, the *I-52* was a puzzle that had become a passion.

wife, Atsuko. Gamo was an engineer, a father of four. He had been ordered to Germany to visit the Daimler-Benz plant and learn how engines were built for torpedo boats.

Japan desperately needed new weapons technology from Germany, and Germany needed raw materials from Japan's empire. But the Axis partners were half a world apart, and all routes across Siberia were closed. Japan had signed a nonaggression pact with the Soviets, but Germany was at war with them. At first German merchant vessels carried the *Yanagi* trade, the Japanese code name for this exchange, but surface shipments became virtual suicide runs; by 1944 scarcely half the ships were getting through.

The only alternative was underwater, and soon both Germany and Japan were modifying submarines to carry Yanagi cargo. The *I-52* was completed at Japan's Kure Naval Yard in 1943. It could hold some 300 tons of freight and steam 21,000 miles without refueling. But the cargo subs fared little better than surface vessels: Only one, *I-8*, completed the voyage from Japan to Europe and back.

In mid-March 1944, under Comdr. Kameo Uno, the *I-52* left Kure Harbor. It stopped in Singapore to take on raw material from Japan's Southeast Asian colonies—2.88 tons of opium, 3 tons of quinine for medical use, and 54 tons of raw rubber. It was manned by 11 officers and 84 enlisted men and carried 14 passengers, 6 from the navy and 8 civilians—a translator and 7 engineers, including Satonobu Gamo. The departure from Singapore was duly noted by U.S. intelligence, which had broken the "purple code" of Japanese diplomacy.

A dreary month passed as the *I-52* worked its way through the Indian Ocean. To avoid detection, it surfaced only at night. During daylight the passengers and off-duty crew had to lie flat, to conserve oxygen.

Gamo had written a letter to his son: "I, your father, have been ordered by the nation to go to a distant place in order to complete an important mission so that Japan will be able to win the war. . . . Satoaki, you have to grow into a great Japanese boy. . . . Think what you should do to become strong and wise."

By May 15 the *I-52* had rounded Africa and entered the Atlantic. As a precaution it was ordered to rendezvous with a German U-boat in mid-ocean, to take on a German pilot and a new radar detector, with two men to operate it, that would enable the sub to sneak into the port of Lorient in German-occupied France.

But by this time the Atlantic was an Allied lake. From around its rim, radio-listening stations relayed positions of Axis ships. The Allies had cracked Germany's Enigma cipher, giving them access to German naval messages.

JONATHAN BLAIR photographed his first story for NATIONAL GEOGRAPHIC in 1966; his most recent article, "From Fins to Feet," appeared last May.

This intelligence, known as Ultra, had already driven the wolf packs of U-boats into hiding, and now it also included the Japanese diplomatic and naval messages to guide Allied antisubmarine forces.

U.S. commanders in Washington, D.C., had pinpointed the *I-52* on a wall chart punctuated with nearly every enemy submarine in the Atlantic. They knew exactly who and what the doomed Japanese vessel carried.

I-52 crossed the Equator on June 4, two days before the invasion of France at Normandy, and got to the rendezvous on schedule at dusk on June 23. The German *U-530* lay in wait.

With both subs surfaced and dangerously exposed, the German commander, Lt. Kurt Lange, launched a rubber dinghy carrying three men—Lieutenant Schäfer, the pilot, and the two radiomen, Petty Officers Schulze and Behrendt—and a wooden box containing the new radar-detection gear. In the heavy swell the box tumbled into the sea, a German seaman later recalled, but a Japanese sailor dived in and retrieved it.

Two and a quarter hours after the subs met, the *U-530* slipped away and set a westerly course. Life and death then hung in the balance as the Japanese submarine stayed surfaced, as if unwilling to give up the luxury of the night air.

Meanwhile 55 miles away Lt. Comdr. Jesse Taylor in his Avenger torpedo plane had been launched from the stubby flight deck of the U.S.S. *Bogue*. The vessel, a bantam-size carrier (CVE) converted from a merchant ship hull, was using information from a special Ultra-guided American antisubmarine command known as the Tenth Fleet.

Taylor, a 28-year-old from Watson, Missouri, was the leader of Composite Squadron 69 (VC-69), one of 14 pilots on the *Bogue* qualified to fly continuous, overlapping night missions. They were *(Continued on page 124)*

Wired to the nerves of *Mir 1,* Viktor Nischeta (below) pilots the submersible up from an encounter with the *I-52,* which lies broken on the bottom at 17,190 feet—more than three miles. Built by the U.S.S.R. in the 1980s for deep-sea exploration, the two *Mirs* can go even deeper and have a good safety record—though nothing on the subs is routine, not even casting off (left). "In a *Mir* you tend to be very, very alert," says photographer Jonathan Blair.

Near the rear of the conning tower on the starboard side 1 submersible crews found damage probably caused by one of the depth bombs an American pilot used to attack the submarine as it scrambled to dive. Tidwell led a survey and salvage expedition to the wreck in 1998, hoping to find the two metric tons of gold that was aboard the sub.

New pieces in a wartime puzzle, these photos of the Japanese sub add detail to a portrait that was almost pure speculation until now. First glimpse of the *I-52* came in 1995, after a team assembled by Tidwell calculated its location from war documents and found it using side-scanning sonar. An image from the 1998 survey expedition shows the sub's largely undamaged stern 1 with its propeller guards still intact. Antiaircraft guns 2 point skyward, as they did while the sub lingered on the surface to recharge its batteries after meeting its German counterpart. Damage to the starboard side of the hull forward of the conning tower 3 probably was inflicted by depth bombs. Some of the worst damage was found in the bow 4 where a tangled mass of wires and hoses marks the sub's torpedo room. The vessel may have landed bow first, crushing this section. The torpedo-shaped objects are tanks that supplied air to the torpedo tubes. Just behind them is a compartment, still intact, that may contain the gold, which the Japanese were transporting to their embassy in Berlin.

2

4

extraordinary young men, sifted from many, with the reflexes to land a plane on a dimly lit and heaving platform the size of a vacant lot.

"Kids. We were just kids," said Snuffy Yarrington, flight gunner on the *Bogue* at the age of 22. "But, boy, did you grow up in a hurry."

The squadron was weary. "We'd been out for seven weeks and were running low on food and fuel," remembered Lt. (jg.) William "Flash" Gordon, another pilot. "This was our last mission before we returned home to Norfolk."

As Taylor soared toward his patrol area, Chief Ed Whitlock, the Avenger's radarman, picked up a promising blip. Closing in, they dropped two smoke lights and a purple sonobuoy into the water. Sonobuoys were newly developed floating radio transmitters that relayed underwater sound to a wire recorder in the cockpit.

The sonobuoy began whispering the "slurp, slurp, slurp" of a marine propeller, and soon the Avenger's crew encountered a startling sight—a huge, fully surfaced enemy submarine, steaming at 10 to 12 knots, tossing a heavy wake.

As the *I-52* scrambled to dive, Taylor roared across its bow, wheeled in a figure eight, and dumped two powerful depth bombs on the starboard beam (opposite). Circling back, he swooped down on the telltale boil of white water to deposit a Mark 24 acoustic torpedo, nicknamed Fido. Three minutes later the sounds of destruction echoed in the thin tenor of the sonobuoy. The gunner, Andy Emmons, said it sounded like "paper being crumpled into a ball in your fist."

The commanding officer of the *Bogue*, Captain A. B. Vosseller, deployed a second attack pilot, Flash Gordon, 45 minutes after Taylor's hit. Gordon dropped his own torpedo after picking up prop sounds at the site, and 17 minutes later he heard a sustained explosion.

The *I-52*—reeling from the detonations, seawater ripping through a gaping hole in its pressure hull, bulkheads collapsing, emergency sirens keening, lights fading into a total and merciful darkness—must have spiraled swiftly down as 112 men made their peace with death.

The following day the *Bogue*'s destroyer escorts found debris and a large oil slick on the water. One of them, U.S.S. *Janssen,* salvaged more than a ton of raw rubber, as well as a sandal and grains of rice. Another picked up silk thread and pieces of flesh.

1995 No photographs of the *I-52* have been identified, and for decades its mission was mired in secrecy on both sides of the war. When reams of U.S. military documents were declassified in the early 1990s, Paul Tidwell was among the first to probe the archives.

WILLIAM GORDON COLLECTION

The U.S. Navy sank so many ships in the Atlantic that the Axis powers were forced underwater into cargo-laden subs. A 1944 photo shows one of the teams sent to hit the *I-52:* pilot William "Flash" Gordon, center, gunner Quentin Kelso, left, and radioman Ira Martin.

The son of a Louisiana businessman, Tidwell is a short, gray-haired, and unassuming man of 50, a veteran of Vietnam with a Purple Heart and two Bronze Stars for combat valor in two tours of duty, including the brutal Tet Offensive. A man of resilience and purpose, he can also be opaque and distrustful.

When his eyes first fell on the words "*I-52* is carrying 2 tons of gold" on a document in the National Archives, he quickly turned the page and glanced around the dusty room to see if anyone had noticed his elation.

By U.S. law a salvager working in international waters can claim rights to a wrecked merchant vessel if he retrieves artifacts from the site, but a country retains ownership of its sunken warships. The Japanese government had claimed at least one other World War II wreck, and Tidwell hoped to avoid a claim to the *I-52.* He traveled to Japan and met with families who had lost loved ones on the submarine, promising them that he would respect the site as a grave.

ART BY CHRISTOPHER A. KLEIN, NATIONAL GEOGRAPHIC ARTIST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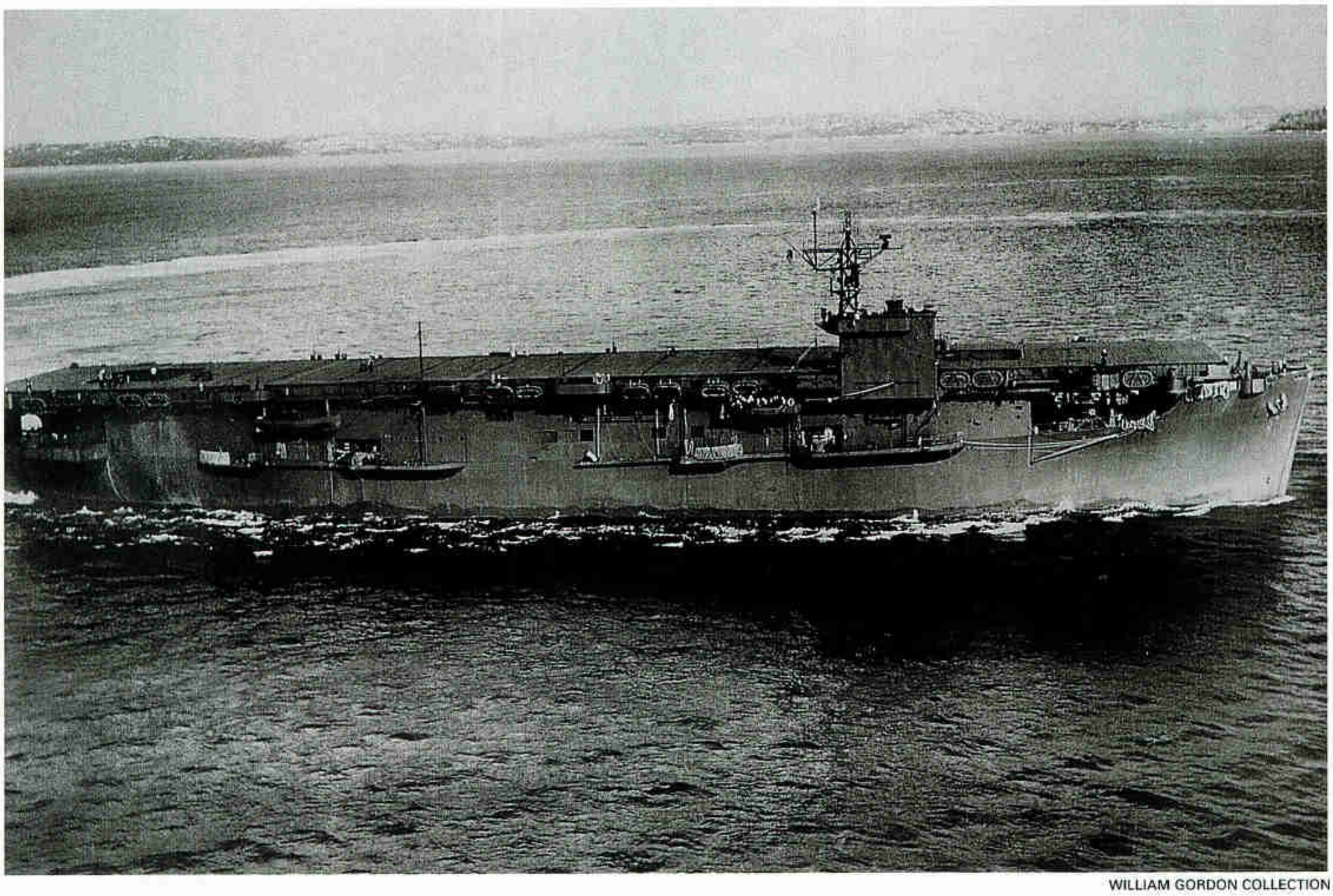


WILLIAM GORDON COLLECTION

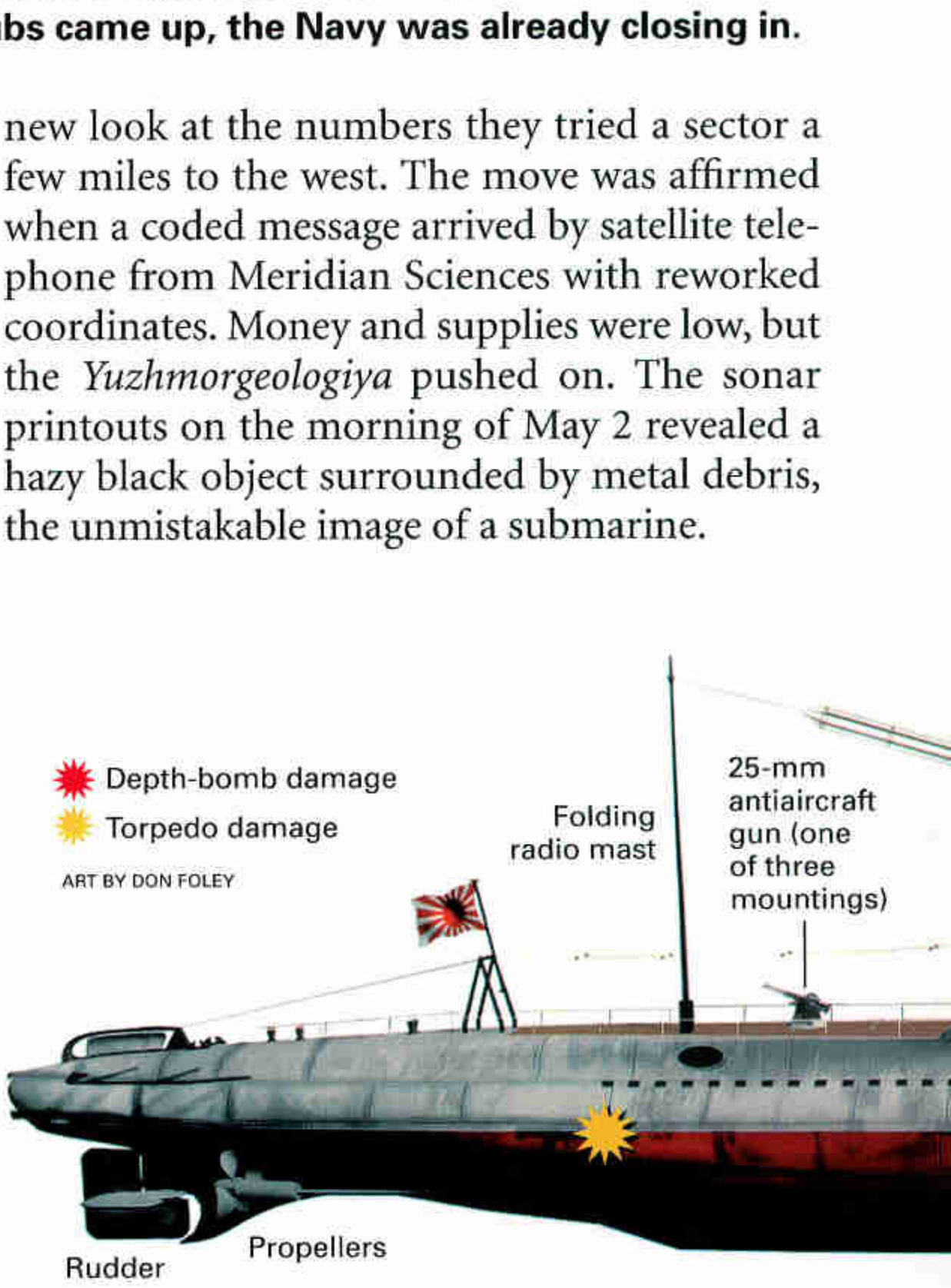
Launched from the U.S.S. *Bogue* (above), the air attack on the *I-52* was no fluke. Earlier in the war Allied cryptanalysts had cracked Axis codes, enabling the Navy to monitor communications about the Japanese vessel. Analysts knew that the 350-foot sub, loaded with war matériel, was bound for Nazi-occupied France and that it planned a surface rendezvous at dusk with a Nazi U-boat, the *U-530*. When the subs came up, the Navy was already closing in.

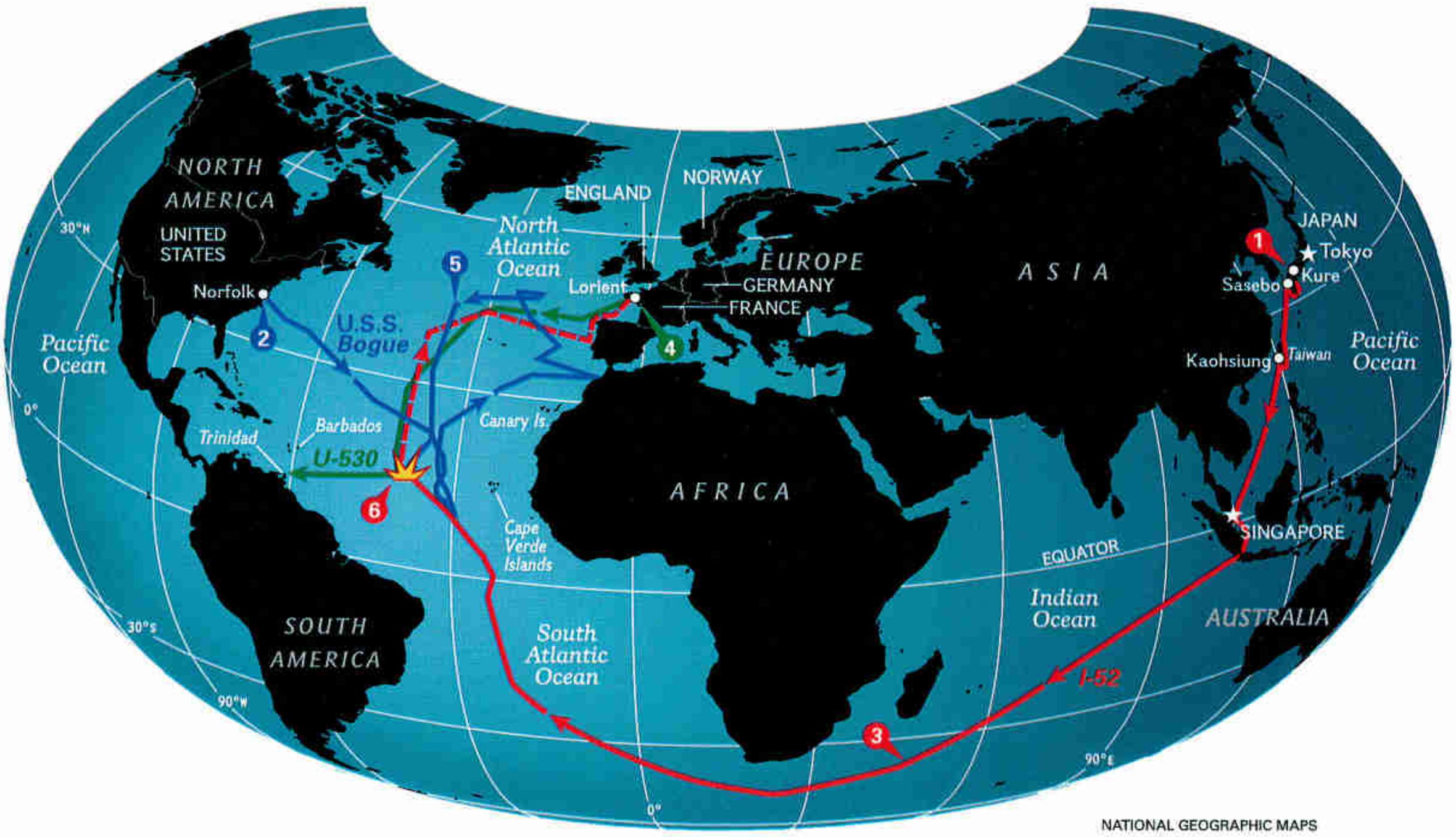
Gradually the treasure hunt became a mission. "I began to get more feeling of the sense of the human tragedy," Tidwell said. "I was really immersed in it."

The timing was right. By 1995 private salvage at great depths was possible because the world's militaries were already dumping their sophisticated Cold War espionage tools—robots, sensors, submersibles—onto the commercial market.

For technical expertise Tidwell contracted with Sound Ocean Systems of Seattle, Washington, which in turn hired specialists from Meridian Sciences. He first took his quest to sea on April 12, 1995, in another hired Russian vessel, the *Yuzhmorgeologiya*. With a technical team managed by Tom Dettweiler, Operation Rising Sun pulled out of Barbados while Meridian's number crunchers were still at work reconstructing the actual routes of the ships and aircraft that took part in the *I-52* action.

For more than two weeks they swept the seafloor with side-scanning sonar. Nothing. Had the *I-52* somehow survived the attack? After a new look at the numbers they tried a sector a few miles to the west. The move was affirmed when a coded message arrived by satellite telephone from Meridian Sciences with reworked coordinates. Money and supplies were low, but the *Yuzhmorgeologiya* pushed on. The sonar printouts on the morning of May 2 revealed a hazy black object surrounded by metal debris, the unmistakable image of a submarine.





NATIONAL GEOGRAPHIC MAPS

1 **March 1944**
I-52 sails.

2 **May 4**
U.S.S. *Bogue* sails.

3 **May 10**
Allied code breakers begin detailed tracking of *I-52* by intercepted radio signals.

4 **May 22**
U-530 sails.

5 **June 15**
U.S.S. *Bogue* receives orders to change course and proceed to new position to attack enemy ships.

6 **June 24**
I-52 is sunk.

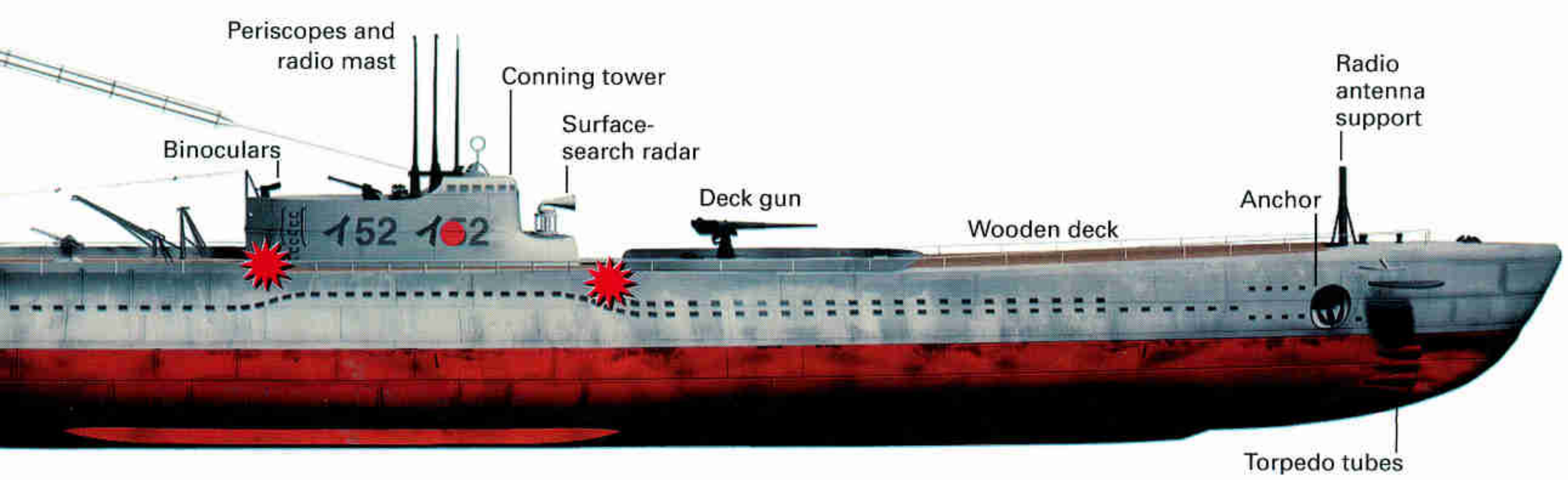
I-52 (Japan)
Intended route of *I-52*
U.S.S. *Bogue*
U-530 (Germany)

"There was no whooping and hollering," remembered Tidwell. "I went up to my cabin and literally collapsed."

The expedition reached home a week later with a cache of photographs, including those of ingot-shaped objects lying on the seafloor. It took Tidwell and his business partner, Guy Zajonc, three years to raise enough money—most of it from James Philippone, a lawyer from Rochester, New York—for a return trip. But the project did not go smoothly.

Tidwell and Zajonc, an attorney from Spokane, Washington, failed in their efforts to find a company to fully salvage the *I-52*. When they settled on the two *Mirs*, it was Plan B: a survey with very limited salvage.

Technical discussions continued to include cutting tools, and money was allocated for them, but Philippone began to feel Tidwell was not leveling with him. "Paul had told me he was



A gaping hole in the starboard side 1 is probably the work of a top secret acoustic torpedo Navy pilots fired at the *I-52*. Visible at the top are remnants of the sub's 290 tons of cargo, some of which was tightly packed between the inner and outer hulls. A similar hole in the wooden foredeck 2 reveals part of the sub's cavernous cargo space, which housed tin, opium, quinine, tungsten, rubber —and gold. As the *I-52* sank, more than a ton of the rubber floated to the surface and was brought aboard the *Bogue* (facing page, top) after being salvaged by the U.S.S. *Janssen*. The rest of the cargo was out of reach until modern technology met the age-old quest for treasure. To defray the cost of exploring the *I-52*, Tidwell recruited supporters willing to gamble that he would recover the gold, worth at least 15 million dollars. When it proved to be beyond his grasp, tempers flared and friendships frayed to the breaking point.

MARINER'S MUSEUM, NEWPORT NEWS, VIRGINIA

Bogue's destroyer escorts found more than a ton of raw rubber, a sandal, silk thread, and pieces of flesh.

going to buy saws and other salvage gear and go for the gold," Philippone told me later. "But I wasn't seeing any of that in the budget."

Just as the *Keldysh* headed into Falmouth, England, to be fitted out for our voyage, Philippone backed out. Zajonc hammered out a new budget, and Philippone relented, but he withdrew nearly a third of the funds. Not much salvage capability remained. Tidwell almost canceled. But were there not ingots simply lying on the seafloor? Surely they could pick some up with the *Mirs*' mechanical arms.

When the *Keldysh* left Las Palmas, Canary Islands, on November 8, 1998, it was long on dreamers and short on doers. Tidwell had brought his wife, Jo Anne, and son, Steven. He had hired two security guards—former Navy Seals with bulging arms—and invited veterans from VC-69: Flash Gordon himself, now 77, and two of his shipmates, Snuffy Yarrington and Jack Gamble. But only four experienced technical experts with Cape Verde Explorations were aboard: Marco Flagg, Tim McGinnis, Geof Howe, and Harry Masson, and their skills would quickly have to gel with Russian systems.

On November 20 the *Keldysh* arrived at the coordinates of the sonar image from 1995. In a brief ceremony Tidwell spoke of sacrifice and threw a dark wreath in the water in honor of the Japanese who had died for their country. "We are all sailors," he said. Flash Gordon wept.

1944 Through the summer the Japanese Embassy in Berlin had grown anxious about the *I-52*, which they had code-named *Momi*, or "evergreen." Strategic items for Japan waited at the dock in Lorient: radar units, bombsights, vacuum tubes, optical glass, steel ball bearings, mercury, machine-gun ammunition, alloy steel for aircraft motors, chemicals, platinum, and at least two newly developed T-5 acoustic torpedoes. Diplomats too were scheduled to return to Japan on the *I-52*.

But the sub's due date, July 25, slipped past, and hope was fading when, on July 30, came a prearranged coded radio signal, QWF—ostensibly from the *I-52* but possibly misinformation from the British—that meant it was 36 hours from port. The assistant naval attaché in Berlin, Yoshikazu Fujimura, had already left Berlin with eight Japanese officials to greet the

A shoe recovered near the wreck appears to be scorched, suggesting the crew's final moments as fires swept through the plunging submarine, consuming its oxygen and setting off secondary explosions. At right, a brass canister found crushed nearby may have been part of an emergency breathing device.

submarine. Encouraged by the QWF signal, they reached Lorient on July 31.

"The most impressive thing was that there were about 200 members of the Hitler Youth in Lorient," Fujimura told Seiichi Nakata, a Japanese television executive, in 1986. "In particular . . . German girls in their early twenties looking very fresh and energetic."

A German warship steamed out of the harbor to meet the Japanese sub. For four days it stood by. On August 8 the naval attaché, Admiral Kojima, radioed Commander Uno from Berlin. "Though we have had no communication from you, we pray for your safety. As it has become dangerous . . . to enter Lorient or other ports along the French coast, proceed to either Trondheim or Bergen in Norway."

By then Allied troops had surrounded Lorient, and Fujimura was in a quandary. "There was no way out except performing hara-kiri. . . . When I said to my juniors, 'What do you think?' they were rubbing their bellies and said that it would hurt."

The Japanese decided to make off in a bus. After a harrowing week-long trip through Allied tank lines, they arrived in Paris on August 8.

Three days later Vice Admiral Abe, Japan's representative to the Axis's Tripartite Council in Berlin, radioed Tokyo: "The disaster which has befallen these liaison submarines one after another, at a time when they were playing such an important role in transportation between Japan and Germany, is indeed an extremely regrettable loss to both countries."

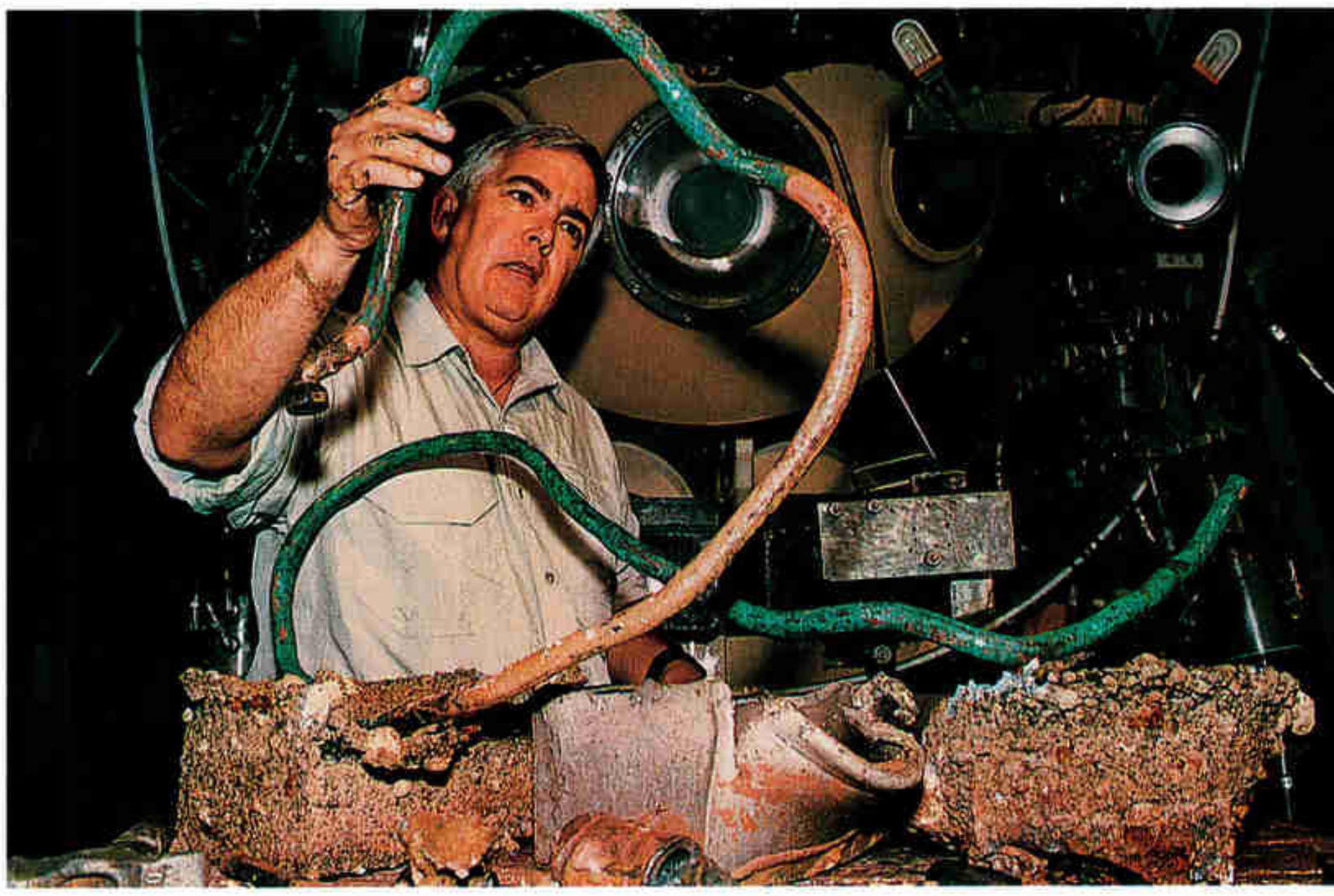
When he was asked about the gold, Fujimura commented, "I do not regret losing . . . gold. I regret that we lost about a hundred sailors. Even now, I wish I could salvage the bodies."

1998 Flesh and bone disintegrate rapidly at such depths; we will not find the bodies. On November 21 Tidwell descends on the first dive in *Mir 2* with two Russian pilots. In *Mir 1* are Marco Flagg and Anatoly Sagalevitch, director of the Russian submersible program. Their mission is to plant acoustic transponders to create an electronic grid to plot key artifacts.

Before the dive Natalya Tumantseva, Anatoly's wife, pushes her way to the railing that overlooks the launch pad. "This is my place," she says. "I've been standing here every time he goes down." She doesn't smile when Anatoly disappears down the hatch with a quick thumbs up. For the Russians, the Tidwell expedition means survival. "For eight years we've been hanging by a thread," she tells me, "with no support from the government, at the end of the food chain."

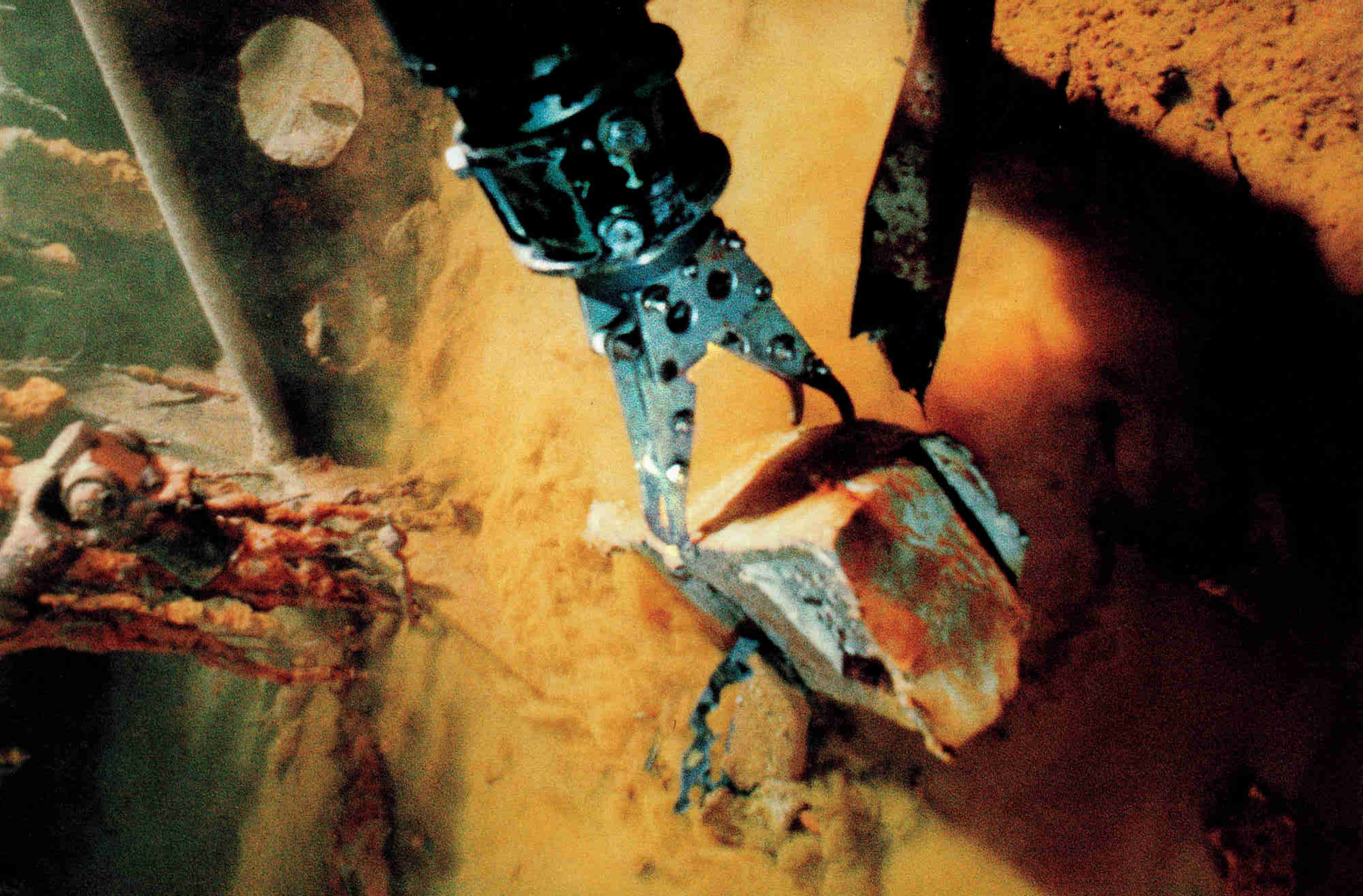
Sixteen hours later the two submersibles return in triumph: We are on target. "Spooky, overwhelming," says Tidwell.

Tidwell has brought up a brick-shaped metal box from the site. That night, behind closed doors, his security men pry it open.



Salvaging what he can from a thwarted quest for gold, project leader Paul Tidwell (above) examines debris from the sub collected by the *Mirs'* mechanical arms. Hearts raced when a *Mir 1* camera found heavy ingots (right) strewn about the wreck—then sank when they were found to be tin.

"Opium," he says next morning. Picturing the *I-52*'s opium as intact and salvageable, he sees a problem. "If all that opium is brought up and made into heroin, it will have a street value of a hundred million dollars. The State Department and the Drug Enforcement Administration know we're diving." Tidwell dumps the substance overboard.



The ship is awash in acrimony, and shouting matches erupt. At tea Tidwell tells me laconically, "I'm on vacation."

On the day of my dive photographer Jonathan Blair, who has been down twice in the submersibles, helps me with a white jumpsuit. The crewmen nod their respect, and Zoryana, the young stewardess, smiles. This morning I am *the one.*

We are hoisted off the ship at 10 a.m., and at 2:23 p.m. we're at the bottom of the sea. Viktor checks the gauge for the water ballast pumps. They're flashing the wrong numbers. He pushes buttons and stares at the numbers, pushes and stares. We're sitting on the bottom, and Viktor doesn't know enough English to reassure me.

"Nyet problem," he says, but his face appears grimmer and grimmer. I think of the backup systems. I draw a picture of pieces of nickel shot, which should be released to gain buoyancy. "Only in emergency," says Viktor. Good, this is not yet an emergency.

By 3:30 Viktor is satisfied, and we at last lift off and float over the debris field: scrap metal, cables, dishes. Suddenly a hulking, nearly intact submarine lies below us, canted against a bank of sediment, much of the wooden deck still in place. The rising sun of the Japanese flag is still clearly visible on the conning tower.

The sub's bow is sheared off near the area of the torpedo tubes, probably from striking the bottom bow first. Forward of the conning tower there is depth-bomb damage, a 15-yard-long cavity of shattered innards: twisted pipes, snapped cables, bent girders. But the mortal wound seems to be near the stern, where a torpedo has blasted cleanly through both the outer and the inner hulls.

As we hover above the submarine, *Mir 2* approaches. We are there in part to provide backlight for the IMAX-format film being shot from the other submersible. "We play Marlon Brando for IMAX," says Viktor, amused and suddenly verbal.

For the next eight hours I scribble notes, take photographs with the still camera bolted onto the mechanical arm, log coordinates of artifacts on the navigation computer, and stare out the port at history's sad residue. At 3 a.m. we are back on the surface.

Days pass. Tidwell and the salvagers spend the first few weeks surveying, but gold is in their eyes, and disappointment mounts as *Mir* after *Mir* returns with nothing but metal boxes, blocks of rubber, odds and ends. The ingots turn out to be tin. Zajonc says, "We need to bring up 40 gold bars to pay off investors." But the gold must be inside the sub, perhaps below its conning tower.

On November 26, Thanksgiving Day, the chef fixes turkey, with the Tidwells assisting. The Philippones help serve it.

Only three more dives are planned. On November 29, Tidwell takes down a flag, a Japanese naval ensign, that he wants to attach to the *I-52.* Millions of lost dollars swim by Philippone as the *Mirs* surface with empty baskets. No gold, and Tidwell's making symbolic gestures. "I'm wasting time," says Philippone.

Now the ship is awash in acrimony, and shouting matches erupt. At tea Tidwell tells me laconically, "I'm on vacation. Jim Philippone has taken over the dives. He says it's his money."

But the next dive, under new management, fails to bring up any loot, and the final dive is needed to retrieve transponders. As we steam back to the Canaries, the estranged partners and the Russian boss are threatening lawsuits. Sagalevitch pulls Tidwell out of a meeting one evening: There's the matter of an unpaid $30,000 port fee in Las Palmas. Not me, says Tidwell, I don't control the money any more. It's Philippone. Bull-hockey, says Philippone.

"Then we go to Kaliningrad," says Sagalevitch, threatening to take the ship back to the *Keldysh*'s home port on the Baltic Sea.

Not long before midnight Tidwell takes a 70-millimeter underwater camera, replacement cost perhaps $30,000, to Sagalevitch's quarters, "as a gift," he tells me. The Russian answers the door in his bathrobe: "Get out of

my office, and lose my address!" Tidwell walks out on deck and chucks the camera overboard.

But cooler heads prevail, and we avoid Christmas in Russia. One evening Tidwell says to me, "In a way I'm glad we didn't recover any gold, because it would tarnish the trip. I can walk away proud because I was able to put the flag on. That meant a lot to me."

Exhaustion peers from his eyes, exposing the truth: For him the treasure hunt has turned into a voyage of contrition. The killing fields of another Asian nation haunt Paul Tidwell. He has done some of the killing. Is it absolution he seeks?

"I'm a nice, slow-talking southern boy," he says softly, "but when I was in Vietnam, I was a different person. Some of my buddies didn't make it back, and I had to write to their mothers. For any country to send out their youth to be killed in wars is terrible. This flag was my letter to those families in Japan."

1944 Before they fled Lorient, German troops destroyed much of the cargo intended for the *I-52*. But one item was not spelled out on the destruction list, which said simply, "____oxide 500 kilograms."

"Obviously uranium oxide," says Tidwell, filling in the blank. If the *I-52* had picked up its cargo, the uranium could have reached Japan by the winter of 1944 and been used in weapons development, though not to build an atomic bomb, as some feared at the time.

Both the Germans and the Japanese had atomic research initiatives, but Hitler curtailed Germany's efforts because he foresaw a quick victory and felt the program would be too costly. The Japanese were trying to find a method to enrich uranium but were in a very early state of this research. Neither was close to building a bomb.

Still, Japan wanted high-grade uranium oxide and depended on Germany to get it. There is evidence that in 1944 a German submarine delivered 500 kilograms of the mineral, but another 500 kilograms was lost at sea on its way to Japan.

The last shipment of uranium left from Kiel March 25, 1945, in a large mine-laying German submarine, *U-234*, under Lt. Johann-Heinrich Fehler. It carried the last of the Yanagi shipments out of Europe—weapons, ammunition, metals, and a disassembled Messerschmitt 262 jet fighter. Mercury and lead were packed in as keel ballast, and in the bow were ten cylinders of uranium oxide.

Among the 12 passengers was Luftwaffe Vice General Ulrich Kessler, the new air attaché to Tokyo, as well as two Japanese technical officers, Comdr. Genso Shoji and Comdr. Hideo Tomonaga, who had been with the delegation sent to Lorient to greet the *I-52*.

On May 8, after the *U-234* had passed from the Norwegian Sea into the North Atlantic, Germany surrendered, and the order came to turn

The Deepest Dive

"It was like going to the moon, only underwater," says photographer Jonathan Blair, standing at far right, after the expedition. "Climbing aboard the *Mir* was like saying good-bye to the world. And once you're down at 17,000 feet, it's very easy to feel as if you're lost in space." Making pictures, of course, was the real challenge for Blair, who has been shooting for the GEOGRAPHIC for more than 30 years and calls this "the toughest trick I've ever tried." To make pictures at this depth and pressure, Blair mounted a heavy-duty Benthos camera loaded with fast film on one of *Mir 1*'s manipulator arms. Using a video monitor to position the camera and lights, he shot about 1,500 still images of the *I-52*. Experts studying Blair's pictures believe they have determined the exact sequence of explosions that brought down the sub.

NOBUKO HANO COLLECTION

Satonobu Gamo left home in Tokyo on a mission so secret he could not even tell his wife, Atsuko.

back to Norway. But Fehler liked his chances better in America and turned his boat and its lethal cargo toward the west.

Japan was still at war, and Fehler confined Tomonaga and Shoji to their quarters. They were found, as Wolfgang Hirschfeld, a radioman on the *U-234*, describes in a memoir, "lying in adjacent cots, their arms linked, breathing stertorously, and couldn't be awakened." An empty bottle of Luminal sleeping tablets was found nearby. After they died, Fehler had the Japanese wrapped in cloth hammocks with Tomonaga's samurai sword and committed them to the deep.

On May 14 the *U-234* surrendered to the U.S.S. *Sutton*. At Portsmouth Naval Base in New Hampshire the arrival of the German U-boat on May 19, 1945, was a sensation. Among the waiting newsmen was William M. Blair of the *New York Times*, Jonathan Blair's father.

Describing the disembarkation of General Kessler, Blair wrote, "Clad in an immaculate gray coat that reached almost to his polished boot tops and a high peaked officer's cap, he appeared almost regal as he stepped to a waiting bus. . . . His cold steel gray eyes, one of them slightly squinting from wearing a monocle, roamed over the guard of Marines. . . . A half-smile was on his lips."

Scientists searched the sub, and on May 27 the office of the chief of naval operations sent a secret memo to naval facilities in New York, describing the cargo as "uranium oxide loaded in gold lined cylinders."

Gold linings were used to protect against radiation leakage but never to pack simple uranium oxide, which is inert and will not emit radiation unless enriched in a fission reactor. Historians agree that Germany did not have such a reactor and that Japan, years away from building an actual bomb, would have no practical use for irradiated material. Why uranium oxide in gold-lined cylinders? It has been suggested that it was a way to transport gold out of the crumbling Third Reich, but no one really knows.

The uranium from the *U-234* was reported to the Manhattan Project, which was frantically developing the first atomic bomb for the United States. But the quantity involved was "of negligible importance for military purposes," according to a 1946 Allied assessment. It almost certainly did not go into the bombs dropped on Japan in August 1945; it was stored in a Brooklyn warehouse that July.

TORIN BOYD

1999 From *Mir 1*'s porthole I had seen the shoe on the bottom of the ocean, a brown lace-up covered with burn marks. Paul Tidwell later picked it up on one of his dives. Now he is by the harbor at Kure, Japan, standing beside a monument to lost submariners. With him are members of the Association of the Bereaved

Families of *I-52*, relatives of those lost on the sub. He gives them the shoe, along with two others, to place in a museum.

In Japan the loss of the *I-52* is cold, sad history, but Tidwell's revelations are well received, for here, as in America, the sinking had at first been a secret. Notice of the death of Satonobu Gamo, the engineer who perished in the sub, reached his wife a full year after he left home.

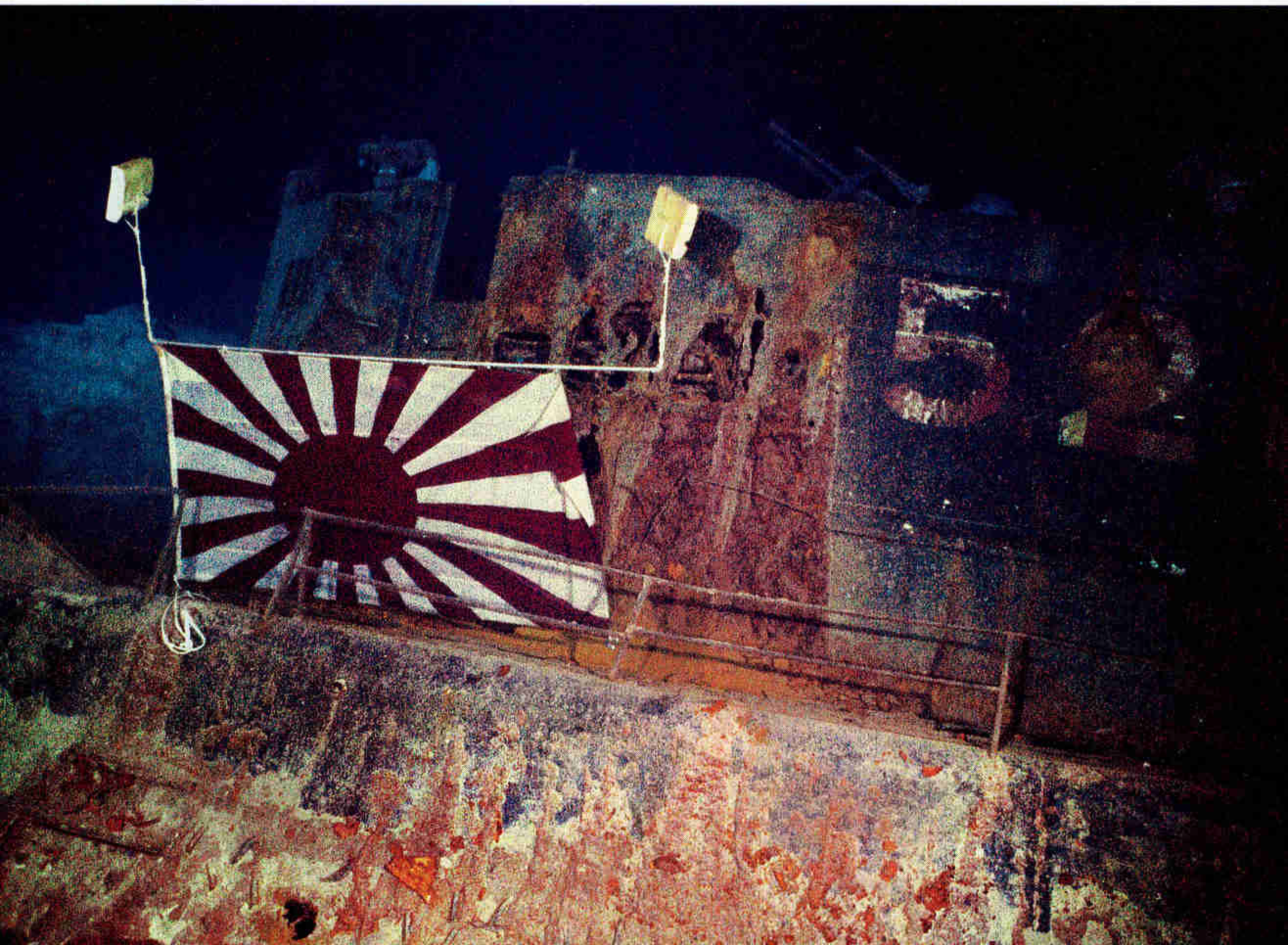
In the U.S. the mission was heralded as the first coordinated kill of a submarine using sonobuoys and acoustic torpedoes. The Navy awarded both Taylor and Gordon the Distinguished Flying Cross for the action and used both of their wire-recordings to train pilots.

But a preliminary analysis of Gordon's original wire, conducted last March, suggested to experts at the Applied Physics Laboratory of Johns Hopkins University that the explosive roar Gordon heard was the torpedo itself, self-destructing, and that the propeller sounds were not those of the *I-52* but actually those of the fleeing German submarine. Taylor's attack probably was enough.

For Paul Tidwell the hunt goes on, despite the project's wake of unpaid bills and stranded investors. "I've been talking to the Japanese government and several major Japanese corporations," he tells me. "We're forming a consortium of companies. We may cut away the conning tower and bring it up."

Gold is still the lure, of course. Delivering it was the mission of the 1944 voyage, recovering it the goal of the 1998 expedition. But salvage will be an enormous undertaking, perhaps more costly than the potential payoff. The gold is there but teasingly beyond reach, beyond the four-inch-thick acrylic of the *Mir* porthole, beyond bone-crushing water pressure, beyond two layers of steel plate. Still no closer than the end of the rainbow. □

Ceremonies honored the dead of the *I-52* both above and below the waterline. On one *Mir* dive Tidwell had a Japanese naval ensign attached to the submarine. Several months later he journeyed to Japan to meet the families of the men who perished. In a brief observance at a memorial to lost submariners in Kure, Japan (left), he presented grieving relatives with three shoes—the only personal effects his expedition recovered.



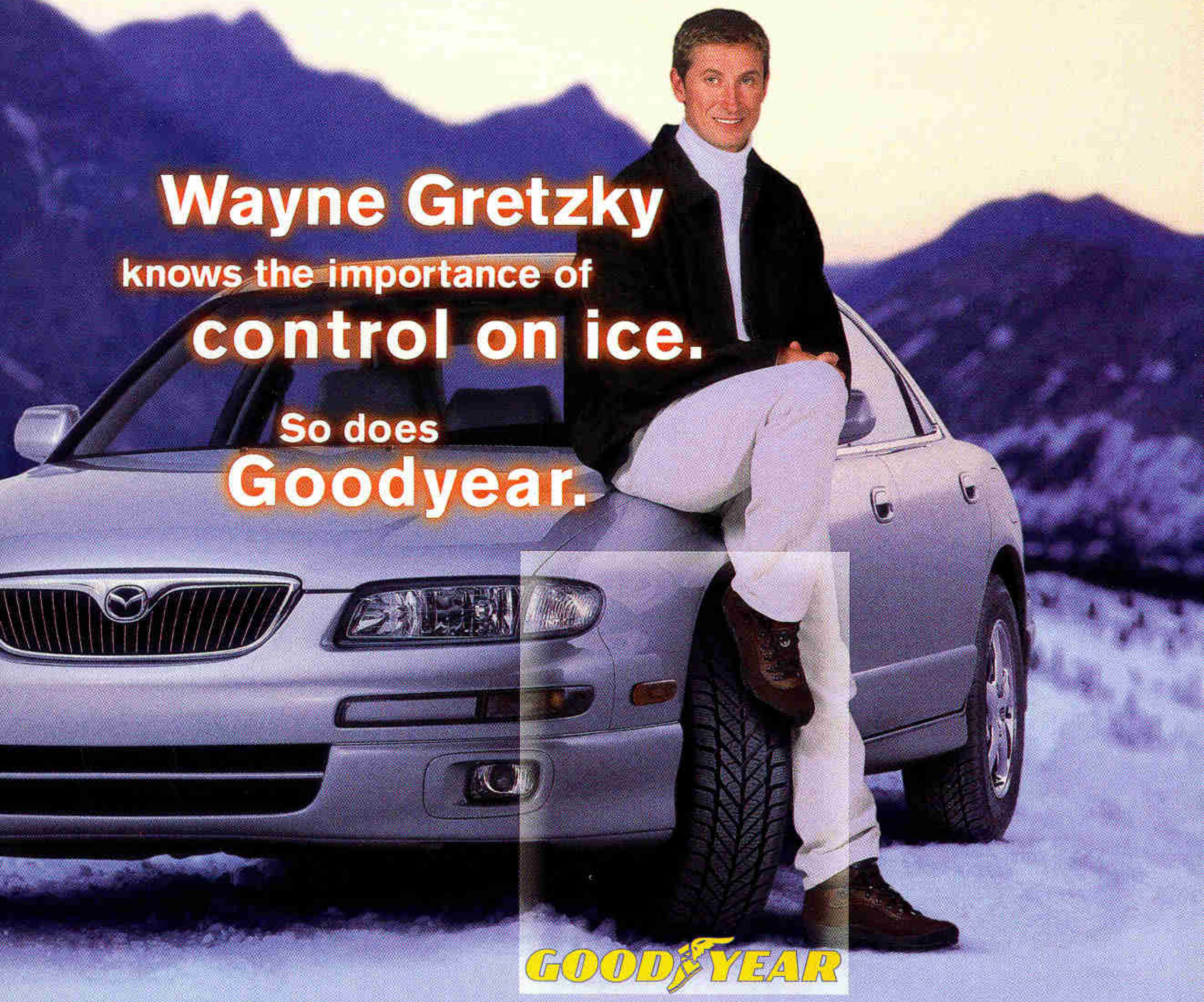
G. M. KER

■ FROM THE GEOGRAPHIC ARCHIVES

Cryptic Passage

The dead didn't rest in Guanajuato, Mexico. Because of limited space at the Panteón Santa Paula cemetery, the bodies of the poor stayed buried just five years unless relatives paid a grave tax. Corpses with accounts in arrears—perhaps mummified by the region's dry climate—were disinterred and hung on pegs, and their old graves were filled with new occupants.

Writer Frank H. Probert reported on the practice in his July 1916 article on Guanajuato. "A winding stair leads to the crypt, where ghastly, mummified remains are placed in a ghostly row, grinning resentment at the curious." Though probably purchased for Probert's article, this photograph has never before been published in the magazine.



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NATIONAL GEOGRAPHIC

Behind the Scenes

BOTH BY MARIA STENZEL

One Bee at a Time for This Year's Winner

La Niña affected more than weather this year; knowing the name of that climate system also clinched the National Geography Bee championship for David Beihl, 13, of South Carolina (above, with parents Penny and Gary), whose prizes are a $25,000 scholarship, a lifetime Society membership, and a trip to Australia donated by corporate sponsor Bank One. David spent months studying geography for the Bee, but that is not the homeschooler's only strong subject. The week after his victory David competed in the National Spelling Bee. Though he placed 22nd there, he was already a winner in our book.

How To Be in the Bee

Some of this year's contestants offered their tips for success in reaching the National Geography Bee:

Spend a lot of time with maps and atlases. —SARAH SOLOMON, VT.

Get examples of previous Bee questions off the National Geographic Society website. —MICHAEL OH, N.Y.

Read! Not just atlases but newspapers and magazines too. —ERIC RODAWIG, S.D.

Be sure to answer all the questions right. —TIM CARR, VA.

Family Tradition

This year's youngest National Geography Bee contestant was also one of this year's best. Ten-year-old Mallika Thampy of Maryland Heights, Missouri, made it to the final rounds. It runs in the family; her brother Eapen represented their state in the 1997 and 1998 Bees.

Little dogs make your apartment seem bigger.

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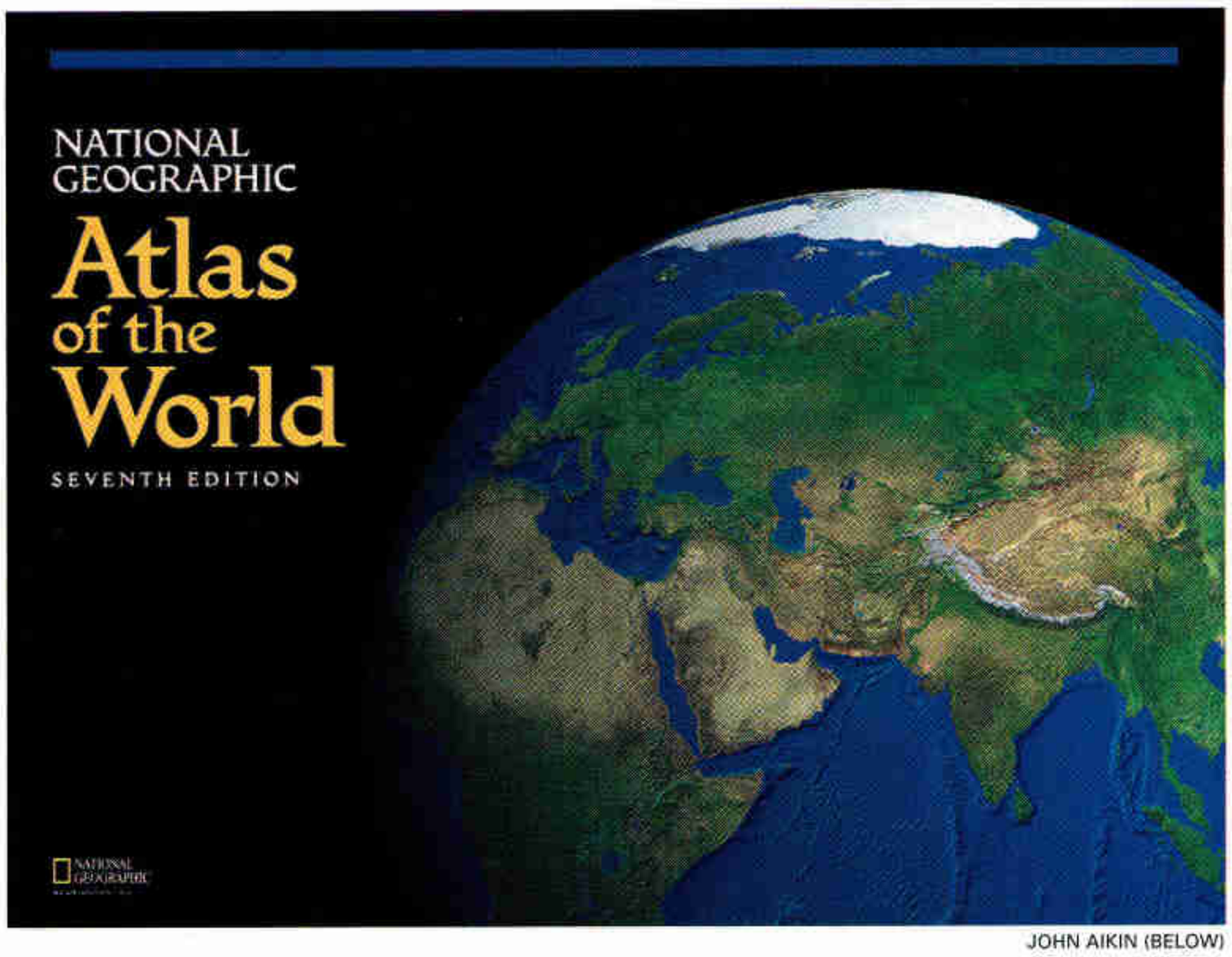
The World on His Shoulders

Eric Lindstrom, NG Maps' editor in charge of quality control for the new seventh edition of the *National Geographic Atlas of the World*, has spent the past few months waking up earlier than usual, his head buzzing with place-names.

"So many spellings have changed since the last edition," says Eric. "They have to be updated everywhere they appear, and some appear in many different places."

Eric should be used to this by now; the 15-year Society veteran also worked on our sixth-edition atlas, where he and his colleagues made some 3,000 changes by pencil to the index alone. This time the work has been put into an extensive computer database, enabling NG Maps to produce the volume about twice as fast as its predecessor. Future updates will be even easier, and Eric Lindstrom will have fewer restless nights.



JOHN AIKIN (BELOW)

International GEOGRAPHICS

Three new local-language editions join our lineup this fall, bringing the total to nine. Faithfully translated from the English-language GEOGRAPHIC, but with added features to arouse local interest, the Polish, German, and French editions will appear on newsstands this month.

TEXT BY MAGGIE ZACKOWITZ

The Yorkie Doodle Dandy

Our April 1999 EXPLORER feature *Battle for Midway* prompted a letter from a veteran with a shaggy-dog story. Serving in the South Pacific during World War II, Bill Wynne acquired a tiny dog that had been found in a New Guinea foxhole. "Smoky" was soon a favorite at field hospitals; she once even helped pull phone cables through a 60-foot underground culvert. Her breed was a mystery until the April 1944 GEOGRAPHIC arrived at the camp. That issue's article on toy dogs featured a champion Yorkshire terrier—then ranked low in the American Kennel Club's popularity polls—that was a ringer for Smoky.

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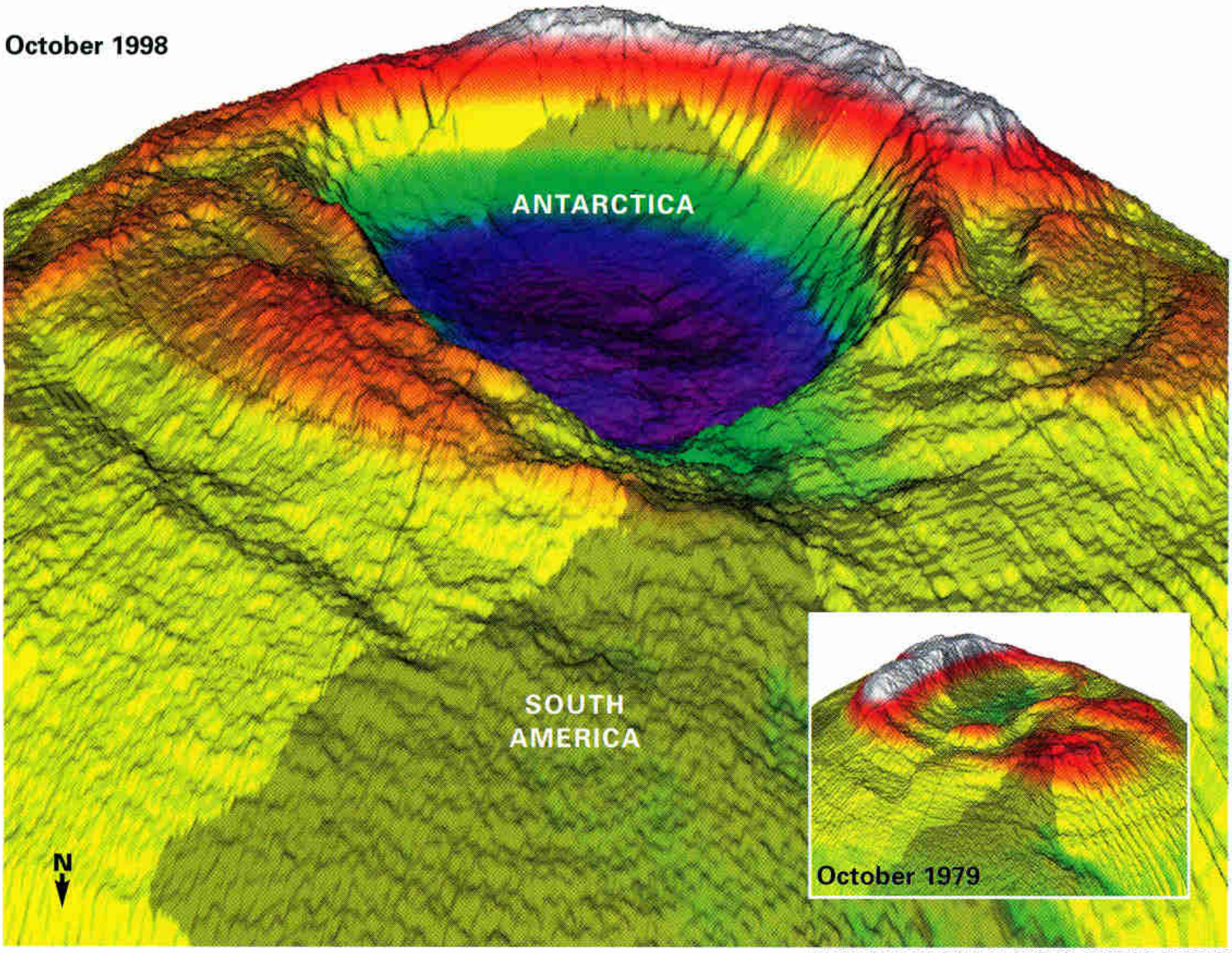
NATIONAL GEOGRAPHIC

CartoGraphic

October 1998



IMAGES PROCESSED BY NASA GODDARD SPACE FLIGHT CENTER

An Ominous Ozone Hole Looms Above Antarctica

Maps usually depict familiar, visible features like mountains and cities. But maps can also reveal invisible—and sometimes disturbing—phenomena.

What appears to be a crater (above) is actually a 3-D image of the Antarctic ozone hole. Created by NASA's Goddard Space Flight Center, the image depicts low atmospheric ozone levels (the so-called hole) as purple depths and high levels as snowcapped peaks.

For over 20 years a satellite instrument called TOMS (Total Ozone Mapping Spectrometer) has mapped the annual ebb and flow of the ozone layer. Since 1979 (inset) TOMS has shown the hole growing steadily larger.

Ozone levels above Antarctica have been monitored since the 1950s, but the rapid growth of the hole during the 1970s and early '80s caught scientists by surprise. The experts knew that chemicals such as chlorofluorocarbons (CFCs), used as refrigerants, react with sunlight in the upper atmosphere to release chlorine atoms. They also knew that those atoms destroy the ozone that protects Earth from harmful solar radiation. But all that was supposed to happen in bright sunshine, not in the winter gloom above Antarctica.

By the late 1980s scientists had an explanation: After doing initial damage to ozone, chlorine atoms become chemically locked within harmless molecules. Some of these collect over Antarctica, where during the winter they come into contact with icy polar clouds and change into less benign forms. The return of sunlight in the Antarctic spring spurs another reaction, setting the chlorine atoms free to continue their destructive cycle.

TEXT BY ALLEN CARROLL
Chief Cartographer

NATIONAL GEOGRAPHIC

*Inter*active

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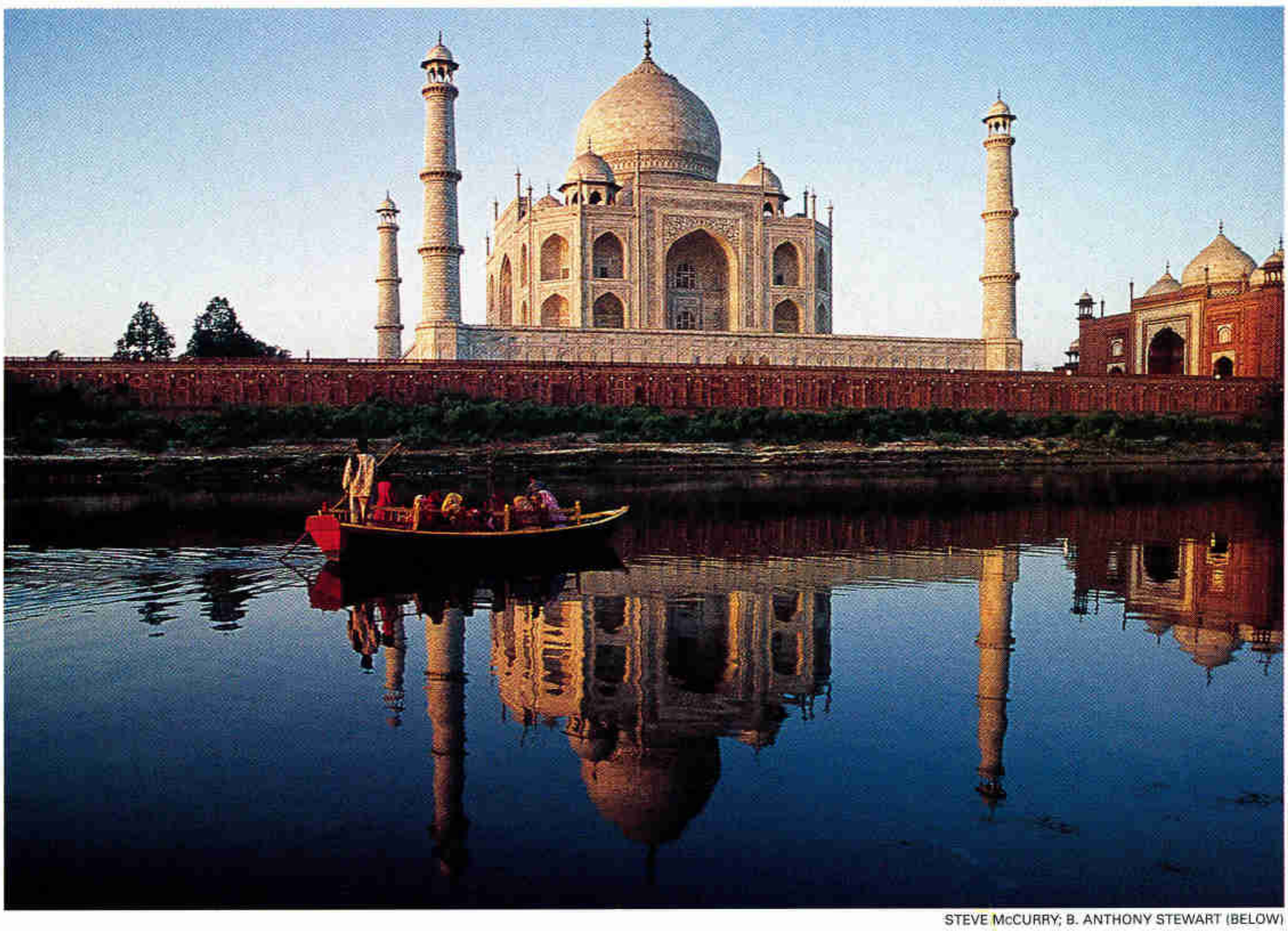

STEVE McCURRY; B. ANTHONY STEWART (BELOW)

50 PLACES OF A LIFETIME

■ ONLINE

Pick Your Place of a Lifetime

Paris, the Taj Mahal (above), the Serengeti—what's your favorite place? Add that cherished spot and why you love it to our poll at *www.ngtraveler.com/50places* and find out if other readers agree. *National Geographic Traveler* consulted the Society's photographers, writers, and editors to develop its list, unveiled at *www.nationalgeographic.com/traveler/1999-07.html.*

■ Is disturbing graves too high a price for archaeological knowledge? Read "Valley of the Mummies" in this issue and share your thoughts at . . . */ngm/9910.*

■ TRIVIA TREK

Unexpected Inspiration

In 1957 the GEOGRAPHIC unwittingly helped a young artist create the iconic pink flamingo lawn ornament. Find his name on our website and tell us at . . . */trek/.*

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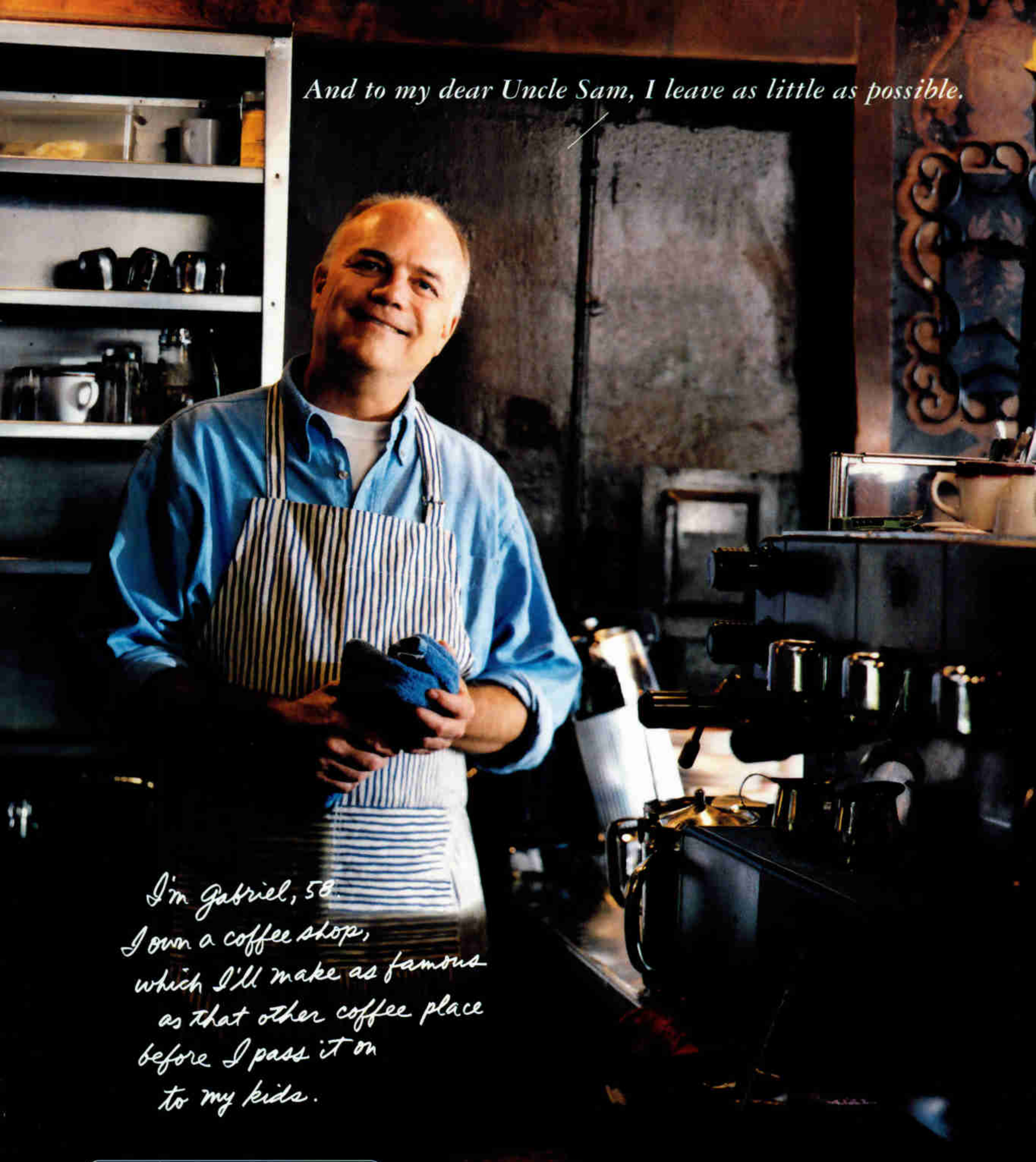
And to my dear Uncle Sam, I leave as little as possible.



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